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COMPUTER SIMULATIONS OF ARTILLERY S&A MECHANISMS (INVOLUTE GEAR TRAIN AND PIN PALLET RUNAWAY ESCAPEMENT)

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Computer simulations of complete safing and arming mechanisms containing pin pallet runaway escapements, two- or three-pass involute gear trains and spin driven rotors were developed. The three motion regimes of the runaway escapement, i.e., coupled motion, free motion and impact, were included. In addition, the ability to consider the effects of pallets with arbitrarily located centers of mass has been introduced. Further, the contact forces of the gear trains and the escapement may be obtained. Simulation runs of actually existing mechanisms were made and good agreement with experimental data was obtained.

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CONTENTS

FIGURES

INTRODUCTION

Computer simulations for complete safing and arming (S&A) mechanisms were developed. Figures 1 and 2 show the essentials of two different configurations of such mechanisms, consisting of spin driven rotors, three pass involute step-up gear trains, and pin pallet runaway escapements. Figures 3 and 4 illustrate two configurations of similar mechanisms which contain two pass involute step-up gear trains.

The present work draws on ideas developed previously by the authors. A dynamic model of a pin pallet runaway escapement driven by a constant torque was developed first (ref 1). The ideas of pivot and tooth-to-tooth friction and the resultant efficiencies of multi-mesh gear trains were then formulated (ref 2), and subsequently, the computational technique of describing mesh initialization at arbitrary points was derived (ref 3).

This report reflects many of the ideas originated in references 1 through 3,[1] in describing combined mechanism trains which are driven by the variable torques of centrifugal rotors. Again, the three motion regimes of the runaway escapement, i.e., coupled motion, free motion, and impact, are considered. In addition, the ability to include the effect of a pallet which has an arbitrarily located center of mass has been introduced. Further, all non-impact contact forces can now be determined for strength considerations.

The complete and detailed derivations of both mathematical models and their configuration variations are given. The associated computer programs are described in detail, with instructions for running them. These programs were extensively tested, both for the configuration no. 1 data (fig. 1) of the three pass M125A1 booster S&A as well as for the configuration no. 2 data (fig. 4) of the two pass M577 SSD mechanism. The M125A1 booster simulation armed in 45 turns for average friction conditions at various spin rates. Under similar conditions, the simulation of the M577 SSD required 31.7 turns for its arming cycle.

DESCRIPTION OF COMPUTER PROGRAMS SANDA3 AND SANDA2

The essential steps of programs SANDA3 and SANDA2, which are listed in appendixes C and D, respectively, follow. This discussion is based on the computer program description in reference 1, which deals with a runaway escapement driven by a constant torque. For the sake of clarity the description in reference 1 is repeated and, whenever necessary, changes in the programs due to the presence of the gear trains and the rotors are identified.

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[1]These models can be adapted to spring driven mechanisms with only minor changes.

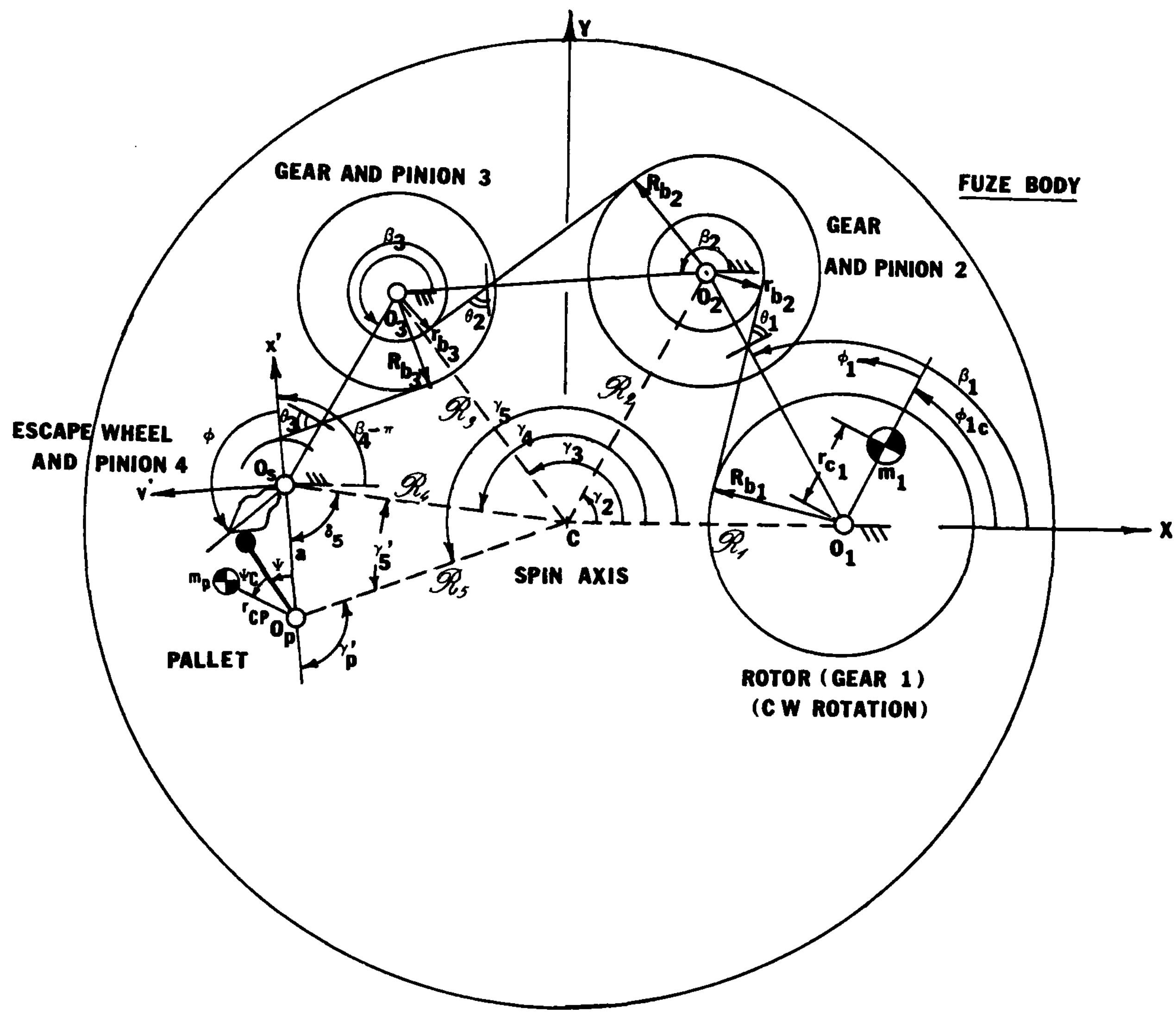

Figure 1. Rotor driven S&A device with three pass step-up gear train, configuration no. 1

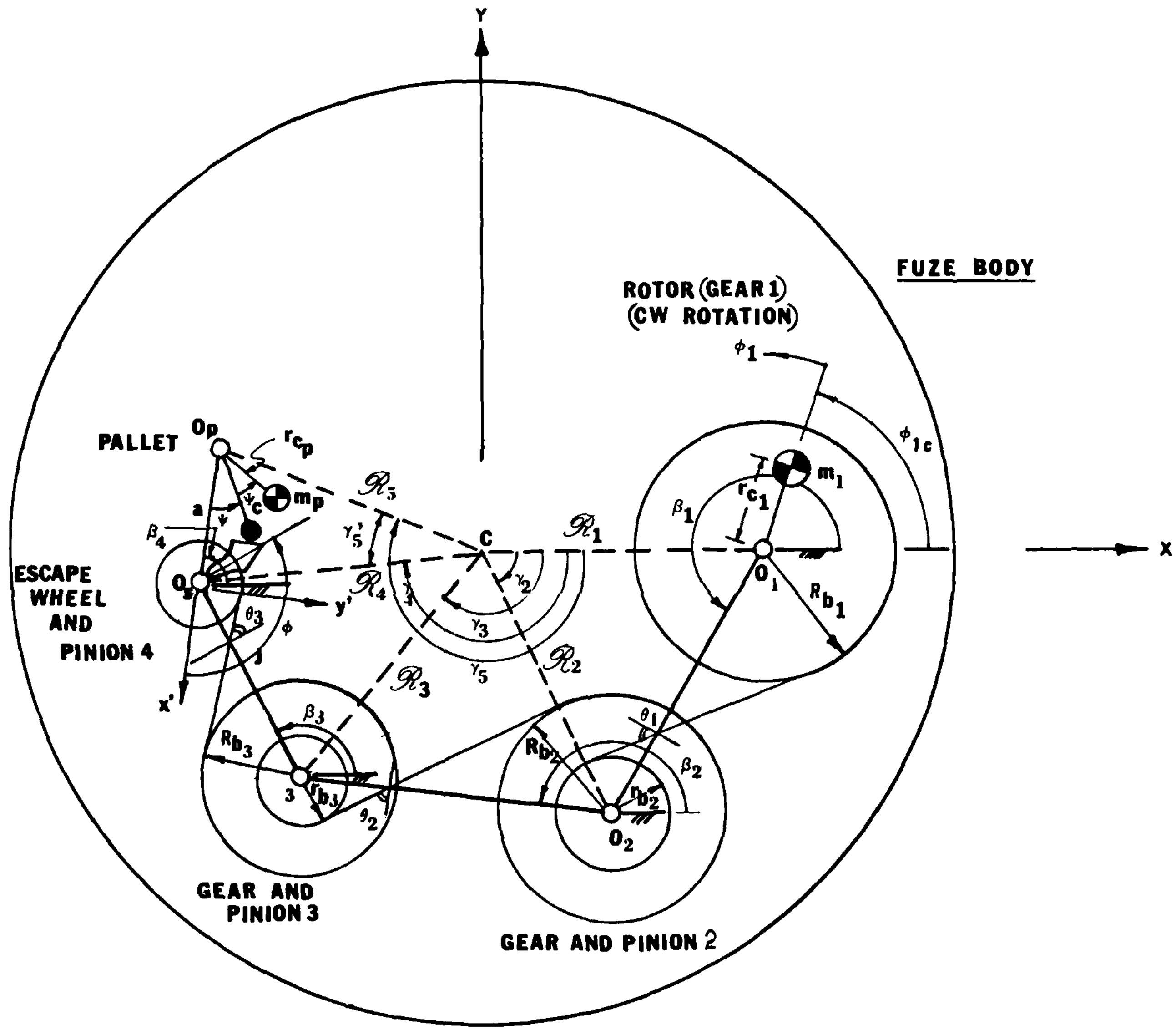

Figure 2. Rotor driven S&A device with three pass step-up gear train, configuration no. 2

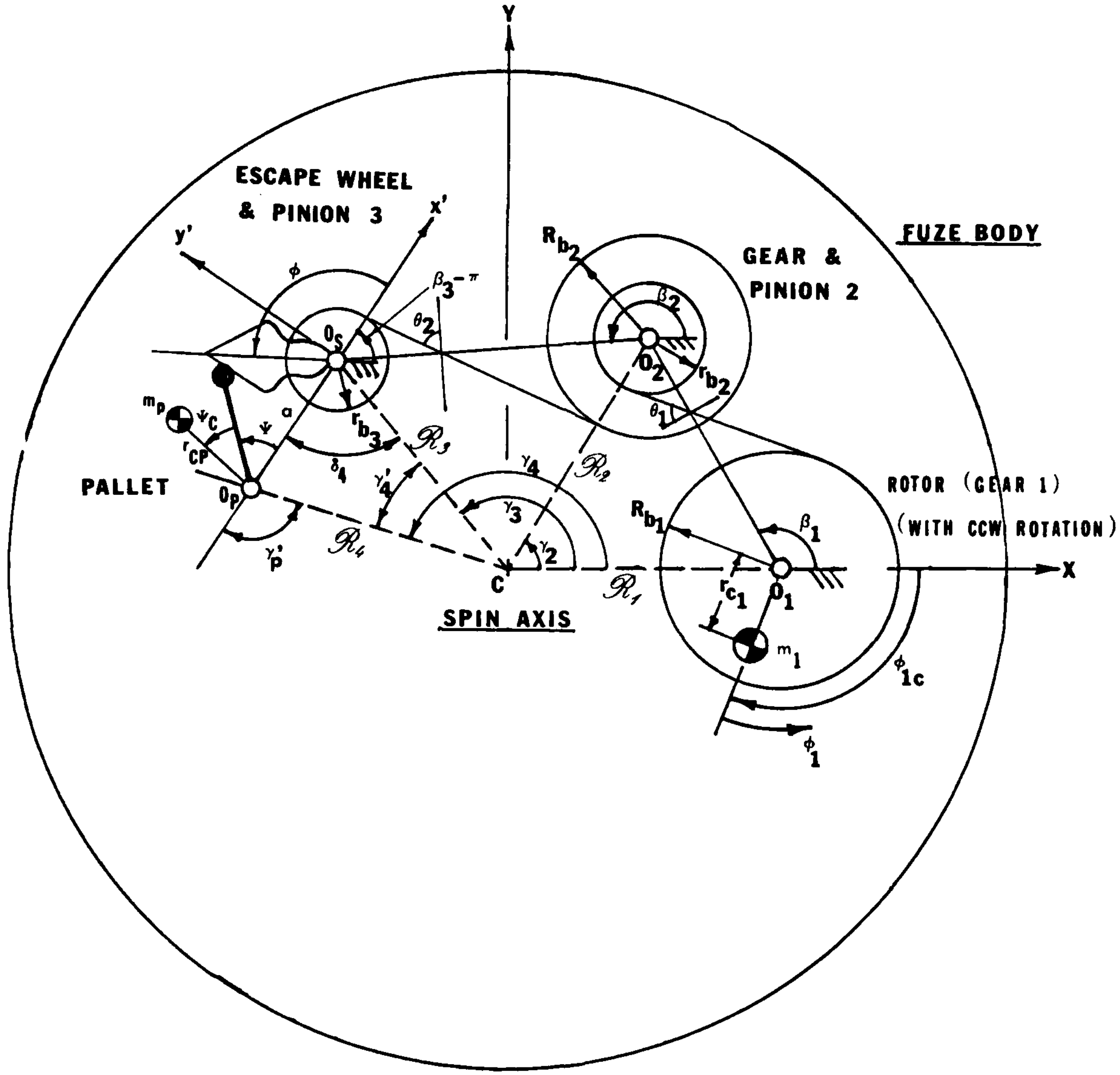

Figure 3. Rotor driven S&A device with two pass step-up gear train, configuration no. 1

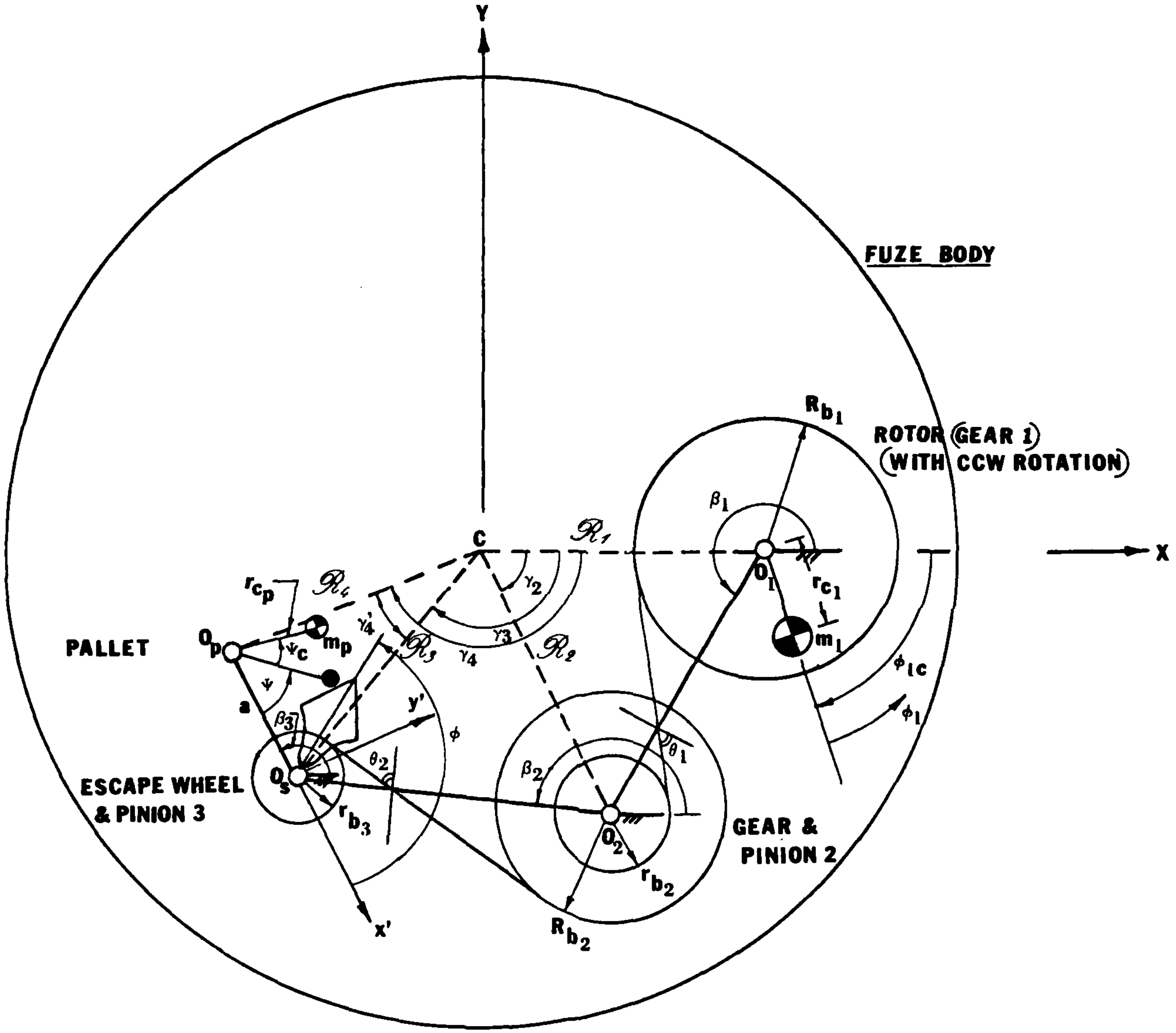

Figure 4. Rotor driven S&A device with two pass step-up gear train, configuration no. 2

Both programs may be used for each of the two possible mechanisms configurations. To differentiate between these configurations, a special input parameter CONFIG must be provided.

The flow chart of the pin pallet runaway escapement part of the programs, is shown in figure 5 which was taken from reference 1. The choice of variable designations was made so that they differ as little as possible from the nomenclature used in the various derivations given in the appendixes of the present report as well as in appendixes A through F and H of reference 1.

Both main programs start with the reading in and writing of the configuration type as well as of all relevant physical data. This is followed by the computation of gear ratios (app A and B), fuze body angles of the applicable configuration, with the help of signum function s_6 (app A and B and ref 2), centrifugal forces (ref 2), earliest and latest possible values of the gear angles by way of subroutine ALFA (ref 2), and the initialization of the gear angles (ref 3). In each case, the simulation begins with entrance coupled motion at a starting angle PHID, which represents the angle ϕ of the escape wheel which is associated with the approximate center of the escape wheel tooth. This angle corresponds to the cumulative escape wheel angle PHITOT of 0°.

Program SANDA3

Coupled Motion (Location 1)

To solve the differential equation of coupled motion (eq A-185, app A), the main program calls on an available fourth order Runge-Kutta routine.[2] The main purpose of the subroutine FCT is to present the second order differential equation in terms of two first order equations to RKGS. PHI(1) and PHI(2) represent the angle ϕ and the angular velocity $\dot{\phi}$, respectively. The computation of all parameters of the differential equation takes place in subroutine FCT as well as in subroutines IN3 and KINEM.

The subroutine KINEM computes current values of g, $\dot{g}$, ψ and $\dot{\psi}$, including the moment arms A_1', B_1', C_1', and D_1' (which are primed in the present report). The associated expressions for the above values are cited in reference 1.

Subroutine IN3 computes various gear mesh parameters and instantaneous mesh contact angles, as well as the signum functions s_1 to s_5. In addition, the parameters A_1 to A_{53}, listed in appendix A, are obtained. (Note that the program uses the symbols AA1, etc., and that the parameters A_{54} to A_{59} are computed in subroutine FCT. This division is dictated by the limited number of arguments permitted in any one subroutine.) Finally, the gear indexing operation (ref 2) is performed with the help of the angle ϕ.

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[2] RKGS Routine, IBM System/360 Scientific Subroutine Package, (360A-CM-0X3) Version III.

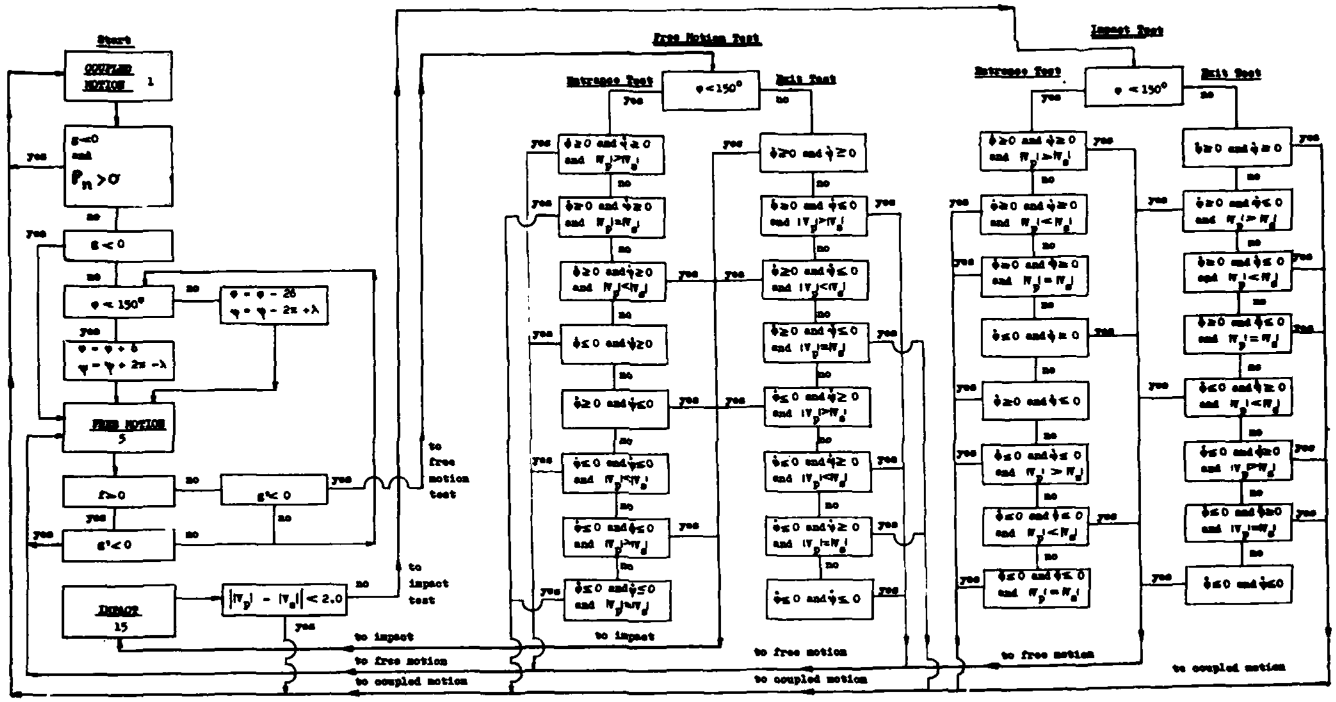


Figure 5. Flow chart for simulation of pin pallet runaway escapement

The manner in which the instantaneous rotor angle, $\phi_{1C} + N_{41}\phi_T$, of the coupled motion differential equation (A-185) must be expressed in subroutine FCT will now be discussed. Recall that ϕ_{1C} is the initial rotor angle, ϕ_T is the total angle of rotation of the escape wheel, and N_{41} stands for the gear ratio between the rotor and the escape wheel. Since the angle ϕ, and consequently the Runge-Kutta variable PHI(1), varies between 140° and 155° during entrance and between 185° to 200° during exit coupled motion, the total escape wheel angle ϕ_T can only be obtained by continuously adding the increments due to each cycle of Runge-Kutta computations. Thus

$$\phi_T \quad = \quad \phi_{TOT} + \Delta\phi \qquad (1)$$

where

ϕ_{TOT} = total escape wheel angle up to a given Runge-Kutta cycle. This is represented by PHITOT in the program.

$\Delta\phi$ = increment of escape wheel during a given Runge-Kutta cycle.

This increment, $\Delta\phi$, is calculated as the difference between the latest value of PHI(1) and its previous value, which has been stored as PHIPR. In this manner, equation 1 becomes

$$\phi_T \quad = \quad \text{PHITOT} + \text{PHI(1)} - \text{PHIPR} \qquad (2)$$

Subroutine FCT also decides on the values of I_{PR} and I_{1R} as required by equations A-88 and A-89 as well as equations A-155 and A-156, respectively. The associated conditional statements assign the larger values for these combined moments of inertia whenever the product of the angular velocity and the angular acceleration is positive, i.e., both quantities have the same sign (app F and paragraph preceding eq A-148).

The associated subroutine OUTP is responsible for printing out the results ϕ, $\dot{\phi}$, and $\ddot{\phi}$ together with the current values of time, g, $\dot{g}$, ψ, $\dot{\psi}$, and PHITOT. Further, all coupled motion contact forces are calculated according to equations A-192 to A-196, and the maximum values of these forces during one rotor cycle are determined. Finally, this subroutine decides, according to the following criteria, whether coupled motion is to be continued. These are:

1. The distance $g < 0$ (ref 1, eq A-12) and because of the nature of the coordinate system g is always negative while the pallet pin makes contact with the escape wheel tooth, and

2. The contact force $P_n > 0$ (eq A-196)

The introduction of the contact force between the escape wheel and the pallet allows the use of simpler controls than those given in reference 1.

Thus, when control is returned to the main program, it is either because the pallet pin has left the end of the tooth and there is no further possibility of coupled motion, or the pin has disengaged from the inside of the tooth. In either case, free motion results and control is eventually shifted to the subroutines FCTF and OUTPF through RKGS (location 5). This is done directly if $g < 0$. If $g > 0$, the main program must decide whether the preceding computations have been made for entrance or for exit action and whether the next contact will occur in enrance or in exit. In the sample mechanism, $g = 0$ when ϕ is approximately 155° for entrance action and approximately 200° for exit action. If $g > 0$ and $\phi < 160^0$, all possibility for entrance contact is ended and ϕ must be incremented by the tooth angle δ (ref 1, figs. 2 and 5), while ψ must be incremented by the angle $(2\pi - \lambda)$ in order to get the initial angles for exit motion. For $g > 0$ and $\phi > 160°$, entrance contact is expected and ϕ must be decremented by the angle 2δ (ref 1, fig 4, where the new entrance tooth no. 3 comes into action). At the same time, the pallet angle ψ must be decremented by $(-2\pi + \lambda)$ for the initial angle of entrance motion. This shift from one side of the pallet to the other must also be observed in connection with the pallet center of mass angle ψ_C (figs. 1 and 2). During entrance action,

$$\psi_C = \text{PSICC} \tag{3}$$

in the program, while during exit action

$$\psi_C = \lambda + \text{PSICC} \tag{4}$$

These indexing operations due to pallet position occur both in coupled and in free motion. They have no effect on the continuous computation of the cumulative escape wheel angle PHITOT.

Free Motion (Location 5)

The differential equations of free motion, as given by equation A-197 for the pallet and equation A-203 for the combined escape wheel, gear train and rotor, are again solved by the Runge-Kutta routine. In order to obtain the magnitudes of the variables ϕ and ψ and their derivatives at identical times, the two independent second-order differential equations are transformed into four simultaneous first-order equations. (While only the two first-order equations associated with each of the two variables are actually coupled, the routine treats all four as if they were coupled and thus produces solutions for identical time increments.) These four expressions, which are presented in subroutine FCTF are given in the following form.

$$\text{DX(1)} = \text{X(2)} : \quad (= \dot{\phi}) \tag{5}$$

$$DX(3) = X(4) : \quad (= \dot{\psi}) \tag{6}$$

$$DX(2) = \frac{1}{A_{64}} \Big[-A_{65}(X(2))^2 + A_{66}X(2) + A_{67}$$

$$+ A_{68}\sin(\phi_{1C} + N_{41}(\phi_T + X(1) - PHIPR))\Big]$$

$$: \quad (= \ddot{\phi}) \tag{7}$$

$$DX(4) = \frac{1}{A_{60}} \Big[-A_{21}(X(4))^2 - A_{61}X(4) - A_{62}$$

$$+ A_{63}\sin(\gamma_p' - \psi - \psi_C)\Big] \quad : \quad (= \ddot{\psi}) \tag{8}$$

Subroutine FCTF also computes the parameters A_{60} to A_{68}[3] and calls on subroutine IN3 for the computation of all gear related parameters.[3]

The associated subroutine OUTPF computes the free motion contact forces according to equations A-209 through A-211, and finds their maxima, after determining the parameters A_{60} to A_{68}. The computation of these latter variables also requires a call on subroutine IN3. In addition to the above, a continuous count of PHITOT is provided in OUTPF. This angle, time, ϕ, $\dot{\phi}$, ψ, $\dot{\psi}$, and the contact forces are printed. This subroutine also makes the decision of whether or not to remain in free motion. The sensing variables, f and $g' = GP$ (ref 1, eq D-7 and D-11), are used for this purpose.

If $f > 0$ and $g' < 0$, free motion is continued without indexing. If $f > 0$ and $g' > 0$, free motion is also continued, but since contact is no longer possible for the component pair for which the previous computations were made, indexing must take place. This is accomplished in the same manner as in coupled motion.

If $f < 0$, control is returned unconditionally to the main program. If it finds that $g' > 0$, indexing takes place and control is given back to the subroutine FCTF. If $g' < 0$, contact is about to take place or has just occurred. This program must decide whether this contact represents just a close approach which is followed by further free motion, an impending impact, or the beginning of coupled motion. To this end, the quantities V_p and V_s (ref 1, eq F-22 and F-23), are computed for the entrance and exit free motion tests.[4] The first three

[3] Whenever $A_{60} = I_{PR} = 0$, the simulation stops because of division by zero. Should this occur, FCTF prints "IPR EQUALS ZERO - SIMULATION TERMINATED."

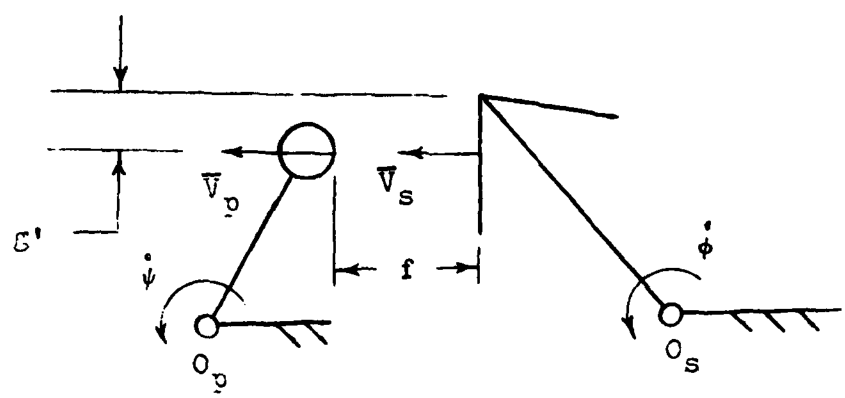
[4] Under the present circumstances, if $\phi < 160°$, only entrance contact can follow; if $\phi > 160°$, exit contact will occur.

cases of the entrance free motion test of the main program are illustrated in figure 6. With both angular velocities ($\dot{\phi}$ = PHI(2) = X(2) and $\dot{\psi}$ = DPSI = X(4)) positive, the following three possibilities exist:

1. If $|V_p| > |V_s|$, the contacting surfaces will separate again, free motion will result, and control must be transferred to subroutine RKGS (location 6), which calls free motion subroutine FCTF.

2. If $|V_p| = |V_s|$, the escape wheel will start driving the pallet in coupled motion, and control must be transferred to subroutine RKGS (location 1 initiates RKGS), which in this case, calls coupled motion subroutine FCT.

3. If $|V_p| < |V_s|$, impact will occur, and control must be given to subroutine IMPACT (location 15).



($\dot{\phi}$ and $\dot{\psi}$ are positive. Distance f is enlarged.)

Figure 6. Entrance free motion test

Impact (Location 15)

The subroutine IMPACT uses the current values of the angular velocities $\dot{\phi}_i$ and $\dot{\psi}_i$ and computes the post impact angular velocities $\dot{\phi}_f$ and $\dot{\psi}_f$, applying equations F-20 and F-21, ref 1. (The moment of inertia of the escape wheel is now expressed according to equation A-212, appendix A of the present report, which refers the rotor, as well as the gear train inertias, to the escape wheel shaft. As shown in reference 1, the tangential impact has been neglected and, therefore, $E_2 = D_1$ and $F_2 = A_1$.)

After control is returned to the main program, it is decided whether free or coupled motion follows the impact. This is accomplished by considering

the post-impact contact point velocities, V_p and V_s, in the impact tests, which are similar to the free motion tests.

If the contact velocities are vectorially equal to each other, or if the absolute value of the difference of their absolute magnitudes is less than 2.0 in./sec (5.08 cm/sec), control is transferred to coupled motion. If these velocities indicate a subsequent separation, which is more usual, computation is transferred to free motion.

Reversal of Gear Train Motion Due to Impact

If the impact torque on the escape wheel is sufficiently large, the motion of the gear train may be temporarily reversed (i.e., the escape wheel angular velocity $\dot{\phi}$ becomes negative). This causes the friction forces between the gear teeth and at the various gear pivots to be reversed in direction. (The normal forces between the gear teeth remain unaffected, and the normal bearing forces are solved for in the usual manner.) This change in the direction of the friction forces is expressed both for coupled and free motion by letting the coefficient of friction μ of all gear train components become negative (app E). This is accomplished in subroutines IN3 and IN2 by the following use of the signum function $\dot{\phi}/|\dot{\phi}|$:

$$\text{MU} = \text{ABS(MU)*}\ \dot{\phi}/|\dot{\phi}| \qquad (9)$$

[The coefficient of friction associated with the escapement interface and the pallet pivot is called μ_1 (read into the program as MU1).] Any motion reversal at these locations is accounted for by the signum functions s_4 and s_5, respectively.

Termination of Computations

Computations are terminated whenever the geared motion of the rotor ends. This corresponds to ϕ = PHICUTD. (See Program SANDA3, General Parameters, below.) The duration of the subsequent unretarded motion of the rotor is assumed to be negligible.

Program SANDA2

Program SANDA2 is very similar to program SANDA3, and where possible, the following description will refer to program SANDA3.

Coupled Motion (Location 1)

To solve the differential equation of coupled motion (app B, eq B-113), the main program calls on the fourth order Runge-Kutta routine. Subroutine FCT presents the second order differential equation in terms of two first order equations to RKGS, which computes PHI(1) and PHI(2) as in SANDA3. The computation of all necessary parameters takes place in FCT and KINEM. In addition, subroutine IN2 is used. This subroutine, which differs from IN3, computes various gear mesh

parameters and contact angles of the two pass train. It further computes the signum functions s_1, s_2, s_4, and s_5 as well as the parameters A_1 to A_{44}, listed in appendix B. The parameters A_{45} to A_{50} are computed in subroutine FCT. Finally, the gear indexing operation is performed with the help of the angle ϕ.

The instantaneous rotor angle now becomes $\phi_{1C} + N_{31}\phi_T$, and is treated in FCT in the same manner as shown by equations 1 and 2. Subroutine FCT also decides on the values of I_{PR} and I_{1R} as required by equations A-88 and A-89 as well as equations B-87 and B-88. The associated conditional statements assign the larger values for these combined moments of inertia whenever the product of the angular velocity and the angular acceleration is positive, i.e., both quantities have the same sign. (See discussion following eq 2.)

The associated subroutine OUTP is responsible for printing out the results ϕ, $\dot{\phi}$, and $\ddot{\phi}$, together with the current values of time, g, $\dot{g}$, ψ, $\dot{\psi}$, and PHITOT. Further, all coupled motion contact forces and their maxima are determined according to equations B-120 to B-123. The coupled motion control criteria given in this subroutine are identical to those described in connection with subroutine OUTP of SANDA3. This is also true of the indexing operations connected with the angles ϕ, ψ, and ψ_C.

Free Motion (Location 5)

The differential equations of free motion, as given in equation B-124 for the pallet and equation B-130 for the combined escape wheel, gear train and rotor, are also solved by the Runge-Kutta routine. The associated four simultaneous first order differential equations, which are given in subroutine FCTF, are similar to those used in SANDA3. (See paragraph before eq 5.).

$$\mathrm{DX}(1) = \mathrm{X}(2) : \quad (= \dot{\phi}) \tag{10}$$

$$\mathrm{DX}(3) = \mathrm{X}(4) : \quad (= \dot{\psi}) \tag{11}$$

$$\begin{aligned} \mathrm{DX}(2) = \frac{1}{A_{55}} \Big[& -A_{56}(\mathrm{X}(2))^2 - A_{57}\mathrm{X}(2) + A_{58} \\ & -A_{59}\sin(\phi_{1C} + N_{31}(\phi_T + \mathrm{X}(1) - \mathrm{PHIPR}))\Big] \\ & : \quad (= \ddot{\phi}) \end{aligned} \tag{12}$$

$$\begin{aligned} \mathrm{DX}(4) = \frac{1}{A_{51}} \Big[& -A_{21}(\mathrm{X}(4))^2 - A_{52}\mathrm{X}(4) - A_{53} \\ & + A_{54}\sin(\gamma_P' - \psi - \psi_C)\Big] \quad : \quad (= \ddot{\psi}) \end{aligned} \tag{13}$$

The subroutine FCTF also computes the parameters A_{51} to A_{59} and calls on subroutine IN2 for the computation of all gear related parameters.

The associated subroutine OUTPF computes the parameters A_{51} to A_{59} in order to obtain the free motion contact forces according to equations B-136 and B-137. In addition, it determines the maxima of these contact forces. These operations also require a call on subroutine IN2. Again, a continuous count of PHITOT is provided in OUTPF, and time, ϕ, $\dot{\phi}$, ψ, $\dot{\psi}$ and the contact forces are caused to be printed together with PHITOT. Whether or not to remain in free motion is decided by the same free motion tests outlined in SANDA3.

Impact (Location 15)

The treatment of the impact phase of the motion is identical to that given in connection with SANDA3. (The moment of inertia of the escape wheel is now expressed according to equation B-138, app B, which refers the rotor as well as gear and pinion no. 2 to the escape wheel shaft.)

Reversal of Gear Train Motion Due to Impact

Any reversal of the gear train due to impact is treated in the same manner as that described in SANDA3 (eq 9). The control of the coefficient of friction, μ, now takes place in subroutine IN2. The coefficient of friction associated with the escapement interface and the pallet pivot is again called μ_1 and is read into the program as MU1.

Termination of Computations

Computations are terminated whenever the geared motion of the rotor ends. This corresponds to ϕ = PHICUTD (Program SANDA2, General Parameters, below). The duration of the subsequent unretarded motion of the rotor is assumed to be negligible.

COMPUTER SIMULATIONS OF EXAMPLE MECHANISMS

Computer simulations of modified M125A1 and M577 spin driven S&A devices are discussed in this section. Both contain appropriately adapted involute gear trains rather than the actual clock gear trains used.[5] Program SANDA3 has been used for the M125A1 mechanism, which has configuration type no. 1. Both the program as well as the relevant output are given in appendix C. The simulation of the M577 mechanism, which has configuration no. 2, was accomplished with the help of SANDA2. This program, as well as associated output, is given in appendix D. Both simulations were run for 30,000 RPM in order to obtain maximum contact forces.

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[5] All gears and pinions have the original number of teeth and diametral pitches. The individual meshes, with unity contact ratio, are designed to operate at standard center distances and have unequal addenda (obtained with program INVOL1 of ref 2).

The data requirements of both programs, an explanation of the various output data, and the manner in which the number of turns to arm results are obtained for a given spin velocity are presented below.

Program SANDA3

Input Data

The required input data is the first portion of the output of Program SANDA3. They represent the mechanism parameters of the M125A1 booster and are listed below both as computer variables and as symbols.

Escapement Parameters.

A	=	a	= 0.2061 in. (5.234 mm)	= distance between pivots O_p and O_S (fig.1)
B	=	b	= 0.192 in. (4.877 mm)	= escape wheel radius
C	=	c	= 0.0788 in. (2.001 mm)	= pallet radius from pivot to center of pin (identical for entrance and exit)
R	=	r	= 0.015 in. (0.381 mm)	= pallet pin radius (identical for entrance and exit)
ALPHA	=	α	= 51°	= escape wheel tooth half angle
CONFIG	=	1		= configuration no. 1
EREST	=	ε	= 0	= coefficient of restitution (high speed motion pictures of runaway escapement suggest totally inelastic impacts)
LAMBDA	=	λ	= 152.144°	= angle between entrance and exit pallet radii
DELTA	=	δ	= 30°	= angle between individual escape wheel teeth

For details of the above nomenclature see reference 1.

Mass Properties of Components.

M1 = m_1	= 0.1155×10^{-3} lb-sec^2/in.	(2.022×10^{-2} kg)	= mass of rotor
M2 = m_2	= 0.686×10^{-5} lb-sec^2/in.	(1.201×10^{-3} kg)	= mass of gear and pinion no. 2
M3 = m_3	= 0.282×10^{-5} lb-sec^2/in.	(4.938×10^{-3} kg)	= mass of gear and pinion no. 3

M4 = m_4	$= 0.252 \times 10^{-5}$ lb-sec^2/in.	(4.412×10^{-4} kg)		= mass of escape wheel and pinion no. 4
MP = m_p	$= 0.359 \times 10^{-5}$ lb-sec^2/in.	(6.286×10^{-4} kg)		= mass of pallet
I1 = I_1	$= 0.1055 \times 10^{-4}$ in.-lb-sec^2	(0.1189×10^{-5} kg-m^2)		= moment of inertia of rotor
I2 = I_2	$= 0.126 \times 10^{-6}$ in.-lb-sec^2	(0.142×10^{-7} kg-m^2)		= moment of inertia of gear and pinion no. 2
I3 = I_3	$= 0.308 \times 10^{-7}$ in.-lb-sec^2	(0.348×10^{-8} kg-m^2)		= moment of inertia of gear and pinion no. 3
I4 = I_4	$= 0.268 \times 10^{-7}$ in.-lb-sec^2	(0.303×10^{-8} kg-m^2)		= moment of of escape wheel and pinion no. 4
IP = I_p	$= 0.245 \times 10^{-7}$ in.-lb-sec^2	(0.277×10^{-8} kg-m^2)		= moment of inertia of pallet

General Parameters.

RC1	=	r_{C1}	= 0.106 in. (2.692 mm)	= distance from rotor pivot to center of mass
RCP	=	r_{CP}	= 0	= pallet eccentricity
RHOP	=	ρ_p	= 0.016 in. (0.406 mm)	= pallet pivot radius
RPM	=	30,000		= spin rate
PHI1CD	=	ϕ_{1C}	= 144°	= rotor angle in starting position (fig. 1)
PSICCD	=	ψ_C	= 0°	= eccentricity angle of pallet (fig. 1)
PHID			= 145°	= escape wheel starting angle of initial coupled motion simulation (for choice of this angle, see ref 1)

PHICUTD		= 3600°	= cumulative escape wheel angle, obtained from product of total rotor rotation and gear train ratio. The total rotor rotation for the M125A1 is 76° while the gear ratio is 47.25. Thus, PHICUTD = 76 x 47.25 ≈ 3600°.
MU	= μ	= 0.15	= coefficient of friction of gear train (pivots and tooth-to-tooth contacts, includes escape wheel pivot)
MU1	= μ_1	= 0.15	= coefficient of friction on pallet-escape wheel interface and pallet pivot

Gear Parameter.

PSUBD1 =	P_{d1}	= 44	= diametral pitch of mesh no. 1 (rotor and pinion no. 2)
PSUBD2 =	P_{d2}	= 65	= diametral pitch of mesh no. 2 (gear no. 2 and pinion no. 3)
PSUBD3 =	P_{d3}	= 77	= diametral pitch of mesh no. 3 (gear no. 3 and escape wheel pinion)
NG1 =	N_{G1}	= 42	= number of teeth of rotor (full gear no. 1)
NG2 =	N_{G2}	= 27	= number of teeth of gear no. 2
NG3 =	N_{G3}	= 27	= number of teeth of gear no. 3
NP2 =	N_{P2}	= 8	= number of teeth of pinion no. 2
NP3 =	N_{P3}	= 9	= number of teeth of pinion no. 3
NP4 =	N_{P4}	= 9	= number of teeth of pinion no. 4 (escape wheel pinion)
CAPRP1 =	R_{p1}	= 0.47727 in. (12.1226 mm)	= pitch radius of gear no. 1 (rotor)
CAPRP2 =	R_{p2}	= 0.20769 in. (5.2753 mm)	= pitch radius of gear no. 2
CAPRP3 =	R_{p3}	= 0.17532 in. (4.4531 mm)	= pitch radius of gear no. 3

RP2	=	r_{p2}	= 0.09091 in. (2.3091 mm)	= pitch radius of pinion no. 2
RP3	=	r_{p3}	= 0.06923 in. (1.7584 mm)	= pitch radius of pinion no. 3
RP4	=	r_{p4}	= 0.05844 in. (1.4844 mm)	= pitch radius of pinion no. 4 (escape wheel pinion)
THETA1	=	θ_1	= 20°	= pressure angle of mesh no. 1
THETA2	=	θ_2	= 20°	= pressure angle of mesh no. 2
THETA3	=	θ_3	= 20°	= pressure angle of mesh no. 3
R1	=	$\mathcal{R}_1$	= 0.225 in. (5.715 mm)	= distance of rotor pivot from spin axis
R2	=	$\mathcal{R}_2$	= 0.436 in. (11.074 mm)	= distance of pivot of gear and pinion set no. 2 from spin axis
R3	=	$\mathcal{R}_3$	= 0.504 in. (12.602 mm)	= distance of pivot of gear and pinion set no. 3 from spin axis
R4	=	$\mathcal{R}_4$	= 0.520 in. (13.208 mm)	= distance of pivot of escape wheel from spin axis
R5	=	$\mathcal{R}_5$	= 0.433 in. (10.998 mm)	= distance of pivot of pallet from spin axis
RHO1	=	ρ_1	= 0.062 in. (1.575 mm)	= pivot radius of rotor
RHO2	=	ρ_2	= 0.025 in. (0.635 mm)	= pivot radius of gear and pinion no. 2
RHO3	=	ρ_3	= 0.018 in. (0.457 mm)	= pivot radius of gear and pinion no. 3
RHO4	=	ρ_4	= 0.016 in. (0.406 mm)	= pivot radius of escape wheel
CAPRB1	=	R_{b1}	= 0.44849 in. (11.3916 mm)	= base radius of gear no. 1
CAPRB2	=	R_{b2}	= 0.19517 in. (4.9573 mm)	= base radius of gear no. 2
CAPRB3	=	R_{b3}	= 0.16475 in. (4.1847 mm)	= base radius of gear no. 3
RB2	=	r_{b2}	= 0.08543 in. (2.1699 mm)	= base radius of pinion no. 2
RB3	=	r_{b3}	= 0.06506 in. (1.6525 mm)	= base radius of pinion no. 3
RB4	=	r_{b4}	= 0.05492 in. (1.3950 mm)	= base radius of escape wheel pinion
CAPRO1	=	R_{o1}	= 0.48791 in. (12.3929 mm)	= outside radius of gear no. 1

CAPRO2 = R_{o2} = 0.21579 in. (5.4811 mm) = outside radius of gear no. 2

CAPRO3 = R_{o3} = 0.18216 in. (4.6269 mm) = outside radius of gear no. 3

RO2 = r_{o2} = 0.110 in. (2.7940 mm) = outside radius of pinion no. 2

RO3 = r_{o3} = 0.08089 in. (2.0546 mm) = outside radius of pinion no. 3

RO4 = r_{o4} = 0.06828 in. (1.7343 mm) = outside radius of escape wheel pinion

J1 = J_1 = 0 = initialization parameter for mesh no. 1. (The value of zero corresponds to earliest possible contact of mesh, ref 3.)

J2 = J_2 = 0 = initialization parameter for mesh no. 2

J3 = J_3 = 0 = initialization parameter for mesh no. 3

Output Data

Fuze Geometry. The angles BETA1D = β_1 to BETA4D = β_4 and GAMMA2D = γ_2 to GAMMA5D = γ_5 are printed for checking purposes.

Coupled motion. For each time increment T of the coupled motion, the following variables are evaluated:

PHI = ϕ = instantaneous escape wheel angle (deg)

PHIDOT = $\dot{\phi}$ = escape wheel angular velocity (rad/sec)

G = g = pallet - escape wheel contact position (in.), ref 1

GDOT = $\dot{g}$ = time rate of change of g used to determine the direction of relative sliding (in./sec), ref 1

PSID = ψ = pallet angle (deg)

PSIDOT = $\dot{\psi}$ = pallet angular velocity (rad/sec)

PHITOT = ϕ_T = cumulative escape wheel angle (deg)

F34 = F_{34} = normal contact force of gear no. 3 on pinion no. 4 (lb)

F23 = F_{23} = normal contact force of gear no. 2 on pinion no. 3 (lb)

F12 = F_{12} = normal contact force of gear no. 1 on pinion no. 2 (lb)

PN = P_n = normal contact force between escape wheel and pallet (lb), computed according to equation A-195

PNPSI = $P_{n\psi}$ = normal contact force between escape wheel and pallet (lb), computed according to equation A-196 (serves for checking)

DPHI2 = $\ddot{\phi}$ = escape wheel acceleration (rad/sec^2), Runge-Kutta output

Free Motion. For each time increment T of the free motion, the following variables are evaluated:

PHI = ϕ = instantaneous escape wheel angle (deg)

PHIDOT = $\dot{\phi}$ = escape wheel angular velocity (rad/sec)

PSI = ψ = pallet angle (deg)

PSIDOT = $\dot{\psi}$ = pallet angular velocity (rad/sec)

PHITOT = ϕ_T = cumulative escape wheel angle (deg)

FF12 = F_{F12} = normal contact force of gear no. 1 on pinion no. 2 for free motion (lb)

FF23 = F_{F23} = normal contact force of gear no. 2 on pinion no. 3 for free motion (lb)

FF34 = F_{F34} = normal contact force of gear no. 3 on escape wheel pinion for free motion (lb)

Impact. Just preceding the "IMPACT" label, the program prints the values VP and VS, which stand for the pre-impact velocity components, normal to the escape wheel tooth, of both the pallet and escape wheel contact points (ref 1). Subsequent to the "IMPACT" label, the following variables are evaluated:

PHI = ϕ = instantaneous escape wheel angle (deg), same as before impact

PHIDOT = $\dot{\phi}$ = post-impact escape wheel angular velocity (rad/sec)

PSI = ψ = pallet angle (deg), same as before impact

PSIDOT = $\dot{\psi}$ = post-impact pallet angular velocity (rad/sec)

PHITOT = ϕ_T = cumulative escape wheel angle (deg), same as before impact

VP	=	V_p	=	post-impact normal velocity component of pallet (pin) at contact point (ref 1)
VS	=	V_s	=	post-impact normal velocity component of escape wheel tooth at contact point (ref 1)

In the present program VP is equal to VS since the coefficient of restitution is zero.

Turns-to-Arm and Maximum Contact Forces. The number of turns-to-arm is obtained by the program for that time T_{3600} which corresponds to the escape wheel angle PHICUTD = 3600°. Therefore

$$\text{Number of turns-to-arm} = \frac{RPM}{60} \times T_{3600}$$

Thus, with $T_{3600} \approx 0.09068$ second (the actual time corresponds to 3600.04°) and 30,000 RPM

$$\text{Number of turns-to-arm} = \frac{30,000}{60} \times 0.09068$$

$$= 45.34 \text{ turns}$$

The maximum non-impact contact forces for the total cycle, both for coupled and for free motion, are listed at the end of the output.

Program SANDA2

Input Data

The required input data represent the first portion of the output of program SANDA2. They stand for the following mechanism parameters of the M577 SSD:

Escapement Parameters.

A	=	a	= 0.2097 in. (5.326 mm)	= distance between pivots O_p and O_S
B	=	b	= 0.193 in. (4.902 mm)	= escape wheel radius
C	=	c	= 0.0788 in. (2.001 mm)	= pallet radius from pivot to center of pin (identical for entrance and exit)
R	=	r	= 0.015 in. (0.381 mm)	= pallet pin radius (identical for entrance and exit)
ALPHA	=	α	= 52°	= escape wheel tooth half angle

CONFIG	=	2	= configuration no. 2
EREST	=	ε = 0	= *coefficient of restitution* (high speed motion pictures of runaway escapement suggest totally inelastic impacts)
LAMBDA	=	λ = 152.144°	= angle between entrance and exit pallet radii
DELTA	=	δ = 30°	= angle between individual escape wheel teeth

Details of the above nomenclature are given in reference 1.

Mass Properties of Components.

M1 = m_1	=	0.3531×10^{-4} lb-sec^2/in.	(6.182×10^{-3} kg)	= mass of rotor
M2 = m_2	=	0.3226×10^{-5} lb-sec^2/in.	(5.648×10^{-4} kg)	= mass of gear and pinion no. 2
M3 = m_3	=	0.2656×10^{-5} lb-sec^2/in.	(4.650×10^{-4} kg)	= mass of escape wheel and pinion no. 3
MP = m_p	=	0.2451×10^{-5} lb-sec^2/in.	(4.291×10^{-4} kg)	= mass of pallet
I1 = I_1	=	0.3350×10^{-5} in.-lb-sec^2	(0.3788×10^{-6} kg-m^2)	= moment of inertia of rotor
I2 = I_2	=	0.3750×10^{-7} in.-lb-sec^2	(0.4240×10^{-8} kg-m^2)	= moment of inertia of gear and pinion no. 2
I3 = I_3	=	0.2490×10^{-7} in.-lb-sec^2	(0.2815×10^{-8} kg-m^2)	= moment of inertia of escape wheel and pinion no. 3
IP = I_p	=	0.6572×10^{-7} in.-lb-sec^2	(0.7430×10^{-8} kg-m^2)	= moment of inertia of pallet

General Parameters.

RC1	=	r_{C1} = 0.115 in. (2.921 mm)	= distance from rotor pivot to center of mass
RCP	=	r_{CP} = 0	= pallet eccentricity

RHOP	=	ρ_p	= 0.0155 in. (0.394 mm)	= pallet pivot radius
RPM	=	30,000		= spin rate
PHI1CD	=	ϕ_{1C}	= −122.23°	= eccentricity angle of rotor in starting position (fig. 4)
PSICCD	=	ψ_C	= 0°	= eccentricity angle of pallet (fig. 4)
PHID			= 150°	= escape wheel starting angle of initial coupled motion simulation (for choice of this angle, see pp 7 and 14, ref 1)
PHICUTD			= 1600°	= cumulative escape wheel angle, obtained from product of total rotor rotation and gear train ratio. The total rotor rotation for the M577 is 48.3° while the gear ratio is 33.02. Thus, 48.3 X 33.02 ≈ 1600.
MU	=	μ	= 0.15	= coefficient of friction of gear train (pivots and tooth-to-tooth contacts, includes escape wheel pivot)
MU1	=	μ_1	= 0.15	= coefficient of friction on pallet - escape wheel interface and pallet pivot

<u>Gear Parameters.</u>

PSUBD1	=	P_{d1}	= 44	= diametral pitch of mesh no. 1 (rotor and pinion no. 2)
PSUBD2	=	P_{d2}	= 63.5	= diametral pitch of mesh no. 2 (gear no. 2 and escape wheel pinion)
NG1	=	N_{G1}	= 41	= number of teeth of rotor (full gear no. 1)
NG2	=	N_{G2}	= 29	= number of teeth of gear no. 2
NP2	=	N_{P2}	= 6	= number of teeth of pinion no. 2
NP3	=	N_{P3}	= 6	= number of teeth of pinion no. 3 (escape wheel pinion)
CAPRP1	=	R_{p1}	= 0.46591 in. (11.834 mm)	= pitch radius of gear no. 1 (rotor)

CAPRP2	= R_{p2}	= 0.22835 in. (5.800 mm)	= pitch radius of gear no. 2
RP2	= r_{p2}	= 0.06818 in. (1.732 mm)	= pitch radius of pinion no. 2
RP3	= r_{p3}	= 0.04724 in. (1.200 mm)	= pitch radius of pinion no. 3 (escape wheel pinion)
THETA1	= θ_1	= 20°	= pressure angle of mesh no. 1
THETA2	= θ_2	= 20°	= pressure angle of mesh no. 2
R1	= $\mathcal{R}_1$	= 0.225 in. (5.715 mm)	= distance of rotor pivot from spin axis
R2	= $\mathcal{R}_2$	= 0.408 in. (10.200 mm)	= distance of pivot of gear and pinion set no. 2 from spin axis
R3	= $\mathcal{R}_3$	= 0.368 in. (9.100 mm)	= distance of pivot of escape wheel from spin axis
R4	= $\mathcal{R}_4$	= 0.361 in. (9.025 mm)	= distance of pivot of pallet from spin axis
RHO1	= ρ_1	= 0.0465 in. (1.181 mm)	= pivot radius of rotor
RHO2	= ρ_2	= 0.0155 in. (0.394 mm)	= pivot radius of gear and pinion no. 2
RHO3	= ρ_3	= 0.0155 in. (0.394 mm)	= pivot radius of escape wheel
CAPRB1	= R_{b1}	= 0.43781 in. (11.120 mm)	= base radius of gear no. 1
CAPRB2	= R_{b2}	= 0.21458 in. (5.450 mm)	= base radius of gear no. 2
RB2	= r_{b2}	= 0.06407 in. (1.627 mm)	= base radius of pinion no. 2
RB3	= r_{b3}	= 0.04439 in. (1.128 mm)	= base radius of escape wheel pinion
CAPRO1	= R_{o1}	= 0.47388 in. (12.037 mm)	= outside radius of gear no. 1
CAPRO2	= R_{o2}	= 0.23387 in. (5.940 mm)	= outside radius of gear no. 2
RO2	= r_{o2}	= 0.09373 in. (2.381 mm)	= outside radius of pinion no. 2
RO3	= r_{o3}	= 0.07321 in. (1.860 mm)	= outside radius of escape wheel pinion
J1	= J_1	= 0	= initialization parameter for mesh no. 1. (The value of zero corresponds to earliest possible contact of mesh (ref 3).)

J2 = J_2 = 0 = initialization parameter for mesh no. 2

Output Data

Fuze Geometry. The angles BETA1D = β_1 to BETA3D = β_3 and GAMMA2D = γ_2 to GAMMA4D = γ_4 are printed for checking purposes.

Coupled Motion. For each time increment, T, of the coupled motion, the following variables are evaluated:

PHI = ϕ = instantaneous escape wheel angle (deg)

PHIDOT = $\dot{\phi}$ = escape wheel angular velocity (rad/sec)

G = g = pallet - escape wheel contact position (in.) (ref 1)

GDOT = $\dot{g}$ = time rate of change of g used to determine the direction of relative sliding (in./sec) (ref 1)

PSID = ψ = pallet angle (deg)

PSIDOT = $\dot{\psi}$ = pallet angular velocity (rad/sec)

PHITOT = ϕ_T = cumulative escape wheel angle (deg)

F23 = F_{23} = normal contact force of gear no. 2 on pinion no. 3 (lb)

F12 = F_{12} = normal contact force of gear no. 1 on pinion no. 2 (lb)

PN = P_n = normal contact force between escape wheel and pallet (lb), computed according to equation B-83

PNPSI = $P_{n\psi}$ = normal contact force between escape wheel and pallet (lb), computed according to equation B-84, (serves for checking)

DPHI2 = $\ddot{\phi}$ = escape wheel acceleration (rad/sec^2), Runge-Kutta output

Free Motion. For each time increment, T, of the free motion, the following variables are evaluated:

PHI = ϕ = instantaneous escape wheel angle (deg)

PHIDOT = $\dot{\phi}$ = escape wheel angular velocity (rad/sec)

PSI = ψ = pallet angle (deg)

PSIDOT	=	$\dot{\psi}$	=	pallet angular velocity (rad/sec)
PHITOT	=	ϕ_T	=	cumulative escape wheel angle (deg)
FF12	=	F_{F12}	=	normal contact force of gear no. 1 on pinion no. 2 for free motion (lb)
FF23	=	F_{F23}	=	normal contact force of gear no. 2 on escape wheel pinion for free motion (lb)

Impact. Just preceding the "IMPACT" label, the program prints the values VP and VS, which stand for the pre-impact velocity components, normal to the escape wheel tooth, of both the pallet and escape wheel contact points (ref 1). Subsequent to the "IMPACT" label, the following variables are evaluated:

PHI	=	ϕ	=	instantaneous escape wheel angle (deg), same as before impact
PHIDOT	=	$\dot{\phi}$	=	post-impact escape wheel angular velocity (rad/sec)
PSI	=	ψ	=	pallet angle (deg), same as before impact
PSIDOT	=	$\dot{\psi}$	=	post-impact pallet angular velocity (rad/sec)
PHITOT	=	ϕ_T	=	cumulative escape wheel angle (deg), same as before impact
VP	=	V_p	=	post-impact normal velocity component of pallet (pin) at contact point (ref 1)
VS	=	V_s	=	post-impact normal velocity component of escape wheel tooth at contact point (ref 1)

Note that in the present program VP is equal to VS since the coefficient of restitution is zero.

Turns-to-Arm and Maximum Contact Forces. The result of 27.93 turns to arm at a spin velocity of 30,000 RPM is obtained by the program in a manner similar to that shown in Program SANDA3 under paragraph entitled Turns-to-Arm and Maximum Contact Forces for the M125A1 booster mechanism. (Now the escape wheel angle PHICUTD = 1600°.)

The maximum non-impact contact forces for the total cycle both for coupled and free motion, are listed at the end of the output.

CONCLUSIONS

While it was not the purpose of the present investigation to undertake parametric studies of either of the two mechanisms for which the programs were written, both programs were sufficiently tested to confirm that such studies are possible. They may include variations in masses and moments of inertia of all components, variations of gear, escapement and fuze geometries, as well as various friction conditions.

Test runs for average friction conditions and standard geometries showed that the M577 SSD simulation required 27.9 turns to arm regardless of the assumed spin rate. Under similar conditions, the M125A1 booster model needed 45.3 turns to arm. Both of these values are well within the military specifications for these devices.

The ability to determine the contact forces during coupled and free motion furnishes the foundation for future work concerning the strength of fuze gear teeth. Such work will also have to include the determination of the appropriate dynamic factors due to the impact of the runaway escapement.

A most interesting phenomenon, which may also serve as the starting point of a future investigation, occurred following the first exit impact during the initial motion cycle of the M577 SSD simulation. The preceding coupled motion was initiated closer to the root of the escape wheel tooth than usual, i.e., the starting angle of the escape wheel was chosen to be PHID = 145°, when a more usual value during stable operation is equal to, or larger than 150°. With this entrance starting condition and the resulting higher than usual pallet angular velocity, the exit impact was sufficiently large to reverse the motion of the escape wheel and the gear train. During this backward motion of the escape wheel, its deceleration (i.e., acceleration in the forward direction), due to the influence of the driving rotor, became approximately 20 times larger than usual and all contact forces increased substantially. This increase in forces subsided as soon as the forward motion of the escape wheel was restored. This phenomenon did not occur during normal operation, since once the escapement has become stable coupled motion starts much nearer to the tip of the escape wheel tooth. The resulting smaller free motion angular velocities of the pallet caused less severe impacts and, as a result, prevented motion reversals.

REFERENCES

1. G. G. Lowen and F. R. Tepper, "Dynamics of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.

2. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

3. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Efficiency," Technical Report ARLCD-TR-80024, ARRADCOM, Dover, NJ, November 1981.

APPENDIX A

DYNAMICS OF ROTOR DRIVEN S&A MECHANISM WITH A THREE-PASS INVOLUTE GEAR TRAIN AND A PIN PALLET RUNAWAY ESCAPEMENT

DESCRIPTION OF SYSTEMS AND OUTLINE OF DERIVATIONS

The present appendix gives derivations for a complete mathematical model of an S&A mechanism, consisting of a spin driven rotor, a three pass involute step-up gear train, and a pin pallet runaway escapement. Figures A-1 and A-2 show the two types of configurations to which this model can be adapted.

This work draws to a considerable extent on previous efforts by the authors, i.e., the dynamics of the pin pallet runaway escapement (ref A-1) and the fuze gear train analysis (ref A-2). As in reference A-1 the following three regimes of the mechanism are considered:[A-1]

1. Coupled Motion

The escape wheel is in constant contact with one of the pallet pins while it is driven by the rotor (gear no. 1) through the gear and pinion sets no. 2 and 3. The coupled motion differential equation in the escape wheel variable ϕ is obtained by combining the solutions to the Newtonian force and moment expressions for the individual mechanism components.

2. Free Motion

The pallet and the escape wheel - gear train - rotor systems move independently of each other in this phase of motion. Thus, there results one differential equation for the pallet in the variable ψ , and another one for the combined system in the escape wheel variable ϕ.

3. Impact

The formulation of the impact regime is taken directly from reference A-1, except that now the moment of inertia of the escape wheel and pinion no. 4 also contains the referred mass properties of the rotor and gear and pinion sets no. 2 and 3. This impact simulation is based on the classical angular impulse - momentum model, where a coefficient of restitution is used to account for the energy losses. Since it is assumed that the effect of the impact force between the escape wheel and the pallet is much greater than the effects due to the driving torque of the rotor and the various retarding torques due to friction, the latter are disregarded.

The influence of friction forces is considered both in the coupled and the free motion regimes. There is friction at the escape wheel - pallet interface during coupled motion, and there is friction between the gear teeth and at all pivots during both of these regimes. As in reference 2 the individual pivot friction

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[A-1] For better understanding, consult figures in reference A-1.

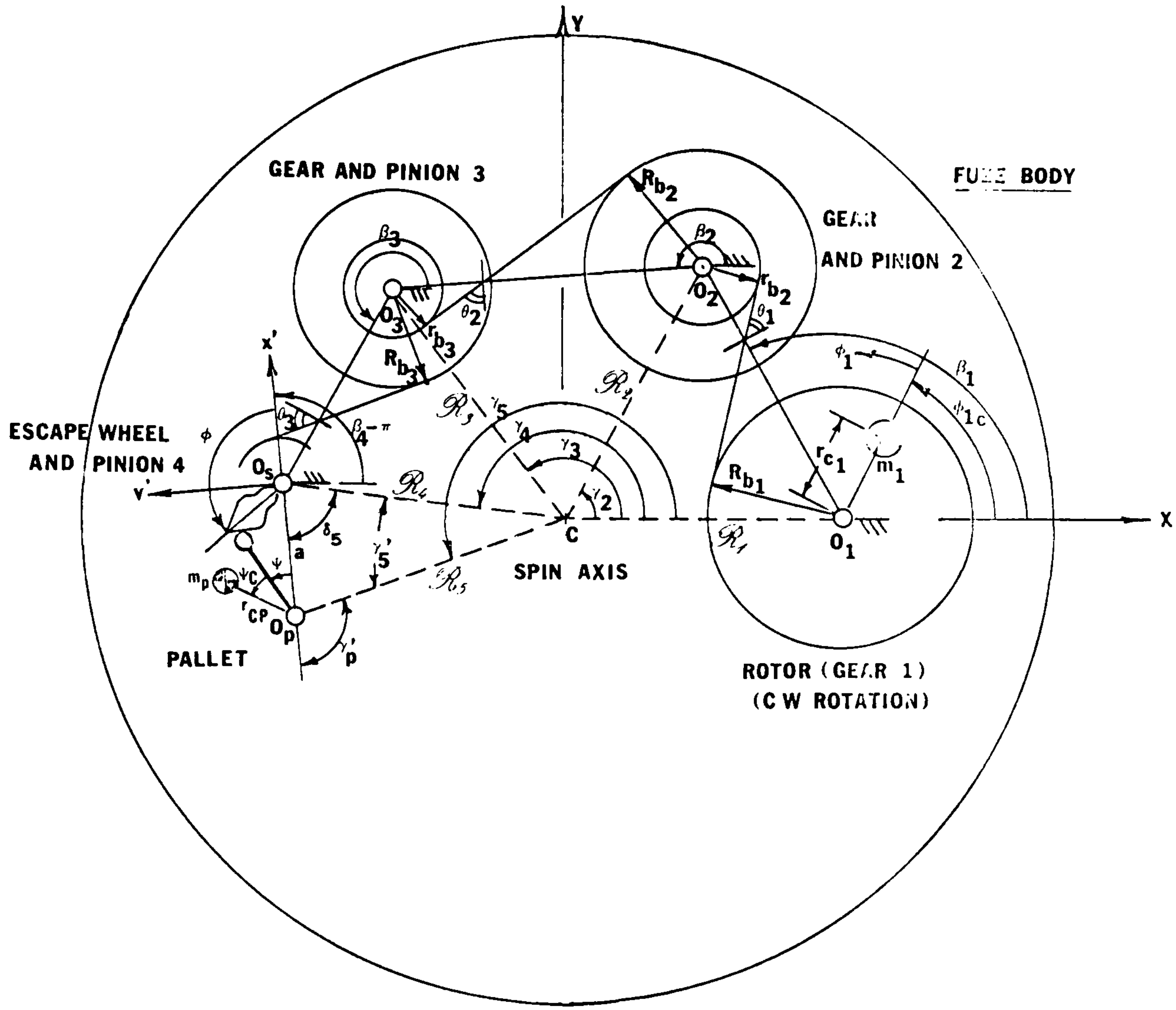

Figure A-1. Rotor driven S&A device with three pass step-up gear train - configuration no. 1

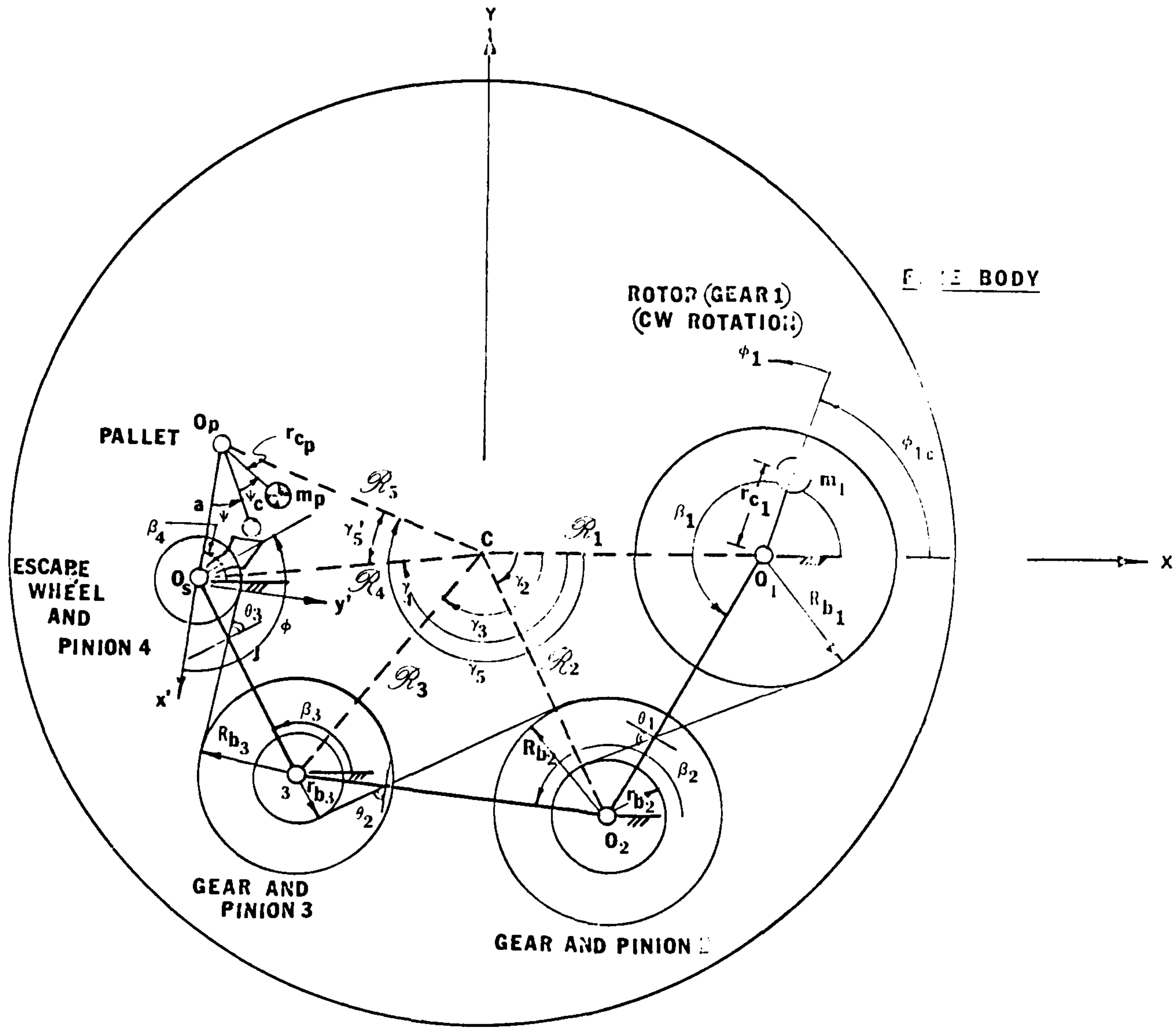

Figure A-2. Rotor driven S&A device with three pass step-up gear train - configuration no. 2

torques are obtained by the algebraic addition of the two friction moments due to the x and y components of the normal bearing forces, rather than by the direct use of the resulting normal forces. This conservative approach to friction is necessary in order to avoid the difficulties which the presence of a square root introduces into the solutions of the various differential equations.

The following briefly outlines the course of the derivations in the individual sections. While the derivations are specifically for configuration no. 1 the results are always applicable to both configurations as long as the appropriate fuze body angles are used.

GEOMETRY OF FUZE BODY CONFIGURATIONS

The following section contains derivations of expressions for the various fuze body angles associated with the pivot holes of both configurations of the three pass step-up gear mechanisms. They represent extensions of previous work pertaining to configuration no. 1 given in reference A-2, appendix A. In addition, relationships between the unit vectors of the body-fixed x-y and x'-y' systems (figures A-1 and A-2) are given in order to make it possible to derive the escapement relationships in the primed coordinate system, whose x'-axis is oriented along the escapement centerline O_p-O_s (ref A-1). Finally, a signum function is introduced so that common programming expressions can be devised for both configurations.

Fuze Body Configuration No. 1

Figure A-3 indicates the following relationships for the angles γ_i, δ_i, and β_i for fuze body configuration no. 1.

Angles γ_i

From

$$(R_{p1} + r_{p2})^2 = \mathcal{R}_1^2 + \mathcal{R}_2^2 - 2\mathcal{R}_1\mathcal{R}_2\cos\gamma_2$$

the following expression is obtained for γ_2

$$\gamma_2 = \cos^{-1}\left[\frac{\mathcal{R}_1^2 + \mathcal{R}_2^2 - (R_{p1} + r_{p2})^2}{2\mathcal{R}_1\ \mathcal{R}_2}\right] \tag{A-1}$$

Similarly, from

$$\gamma_3 = \cos^{-1}\left[\frac{\mathcal{R}_2^2 + \mathcal{R}_3^2 - (R_{p2} + r_{p3})^2}{2\ \mathcal{R}_2\ \mathcal{R}_3}\right] \tag{A-2}$$

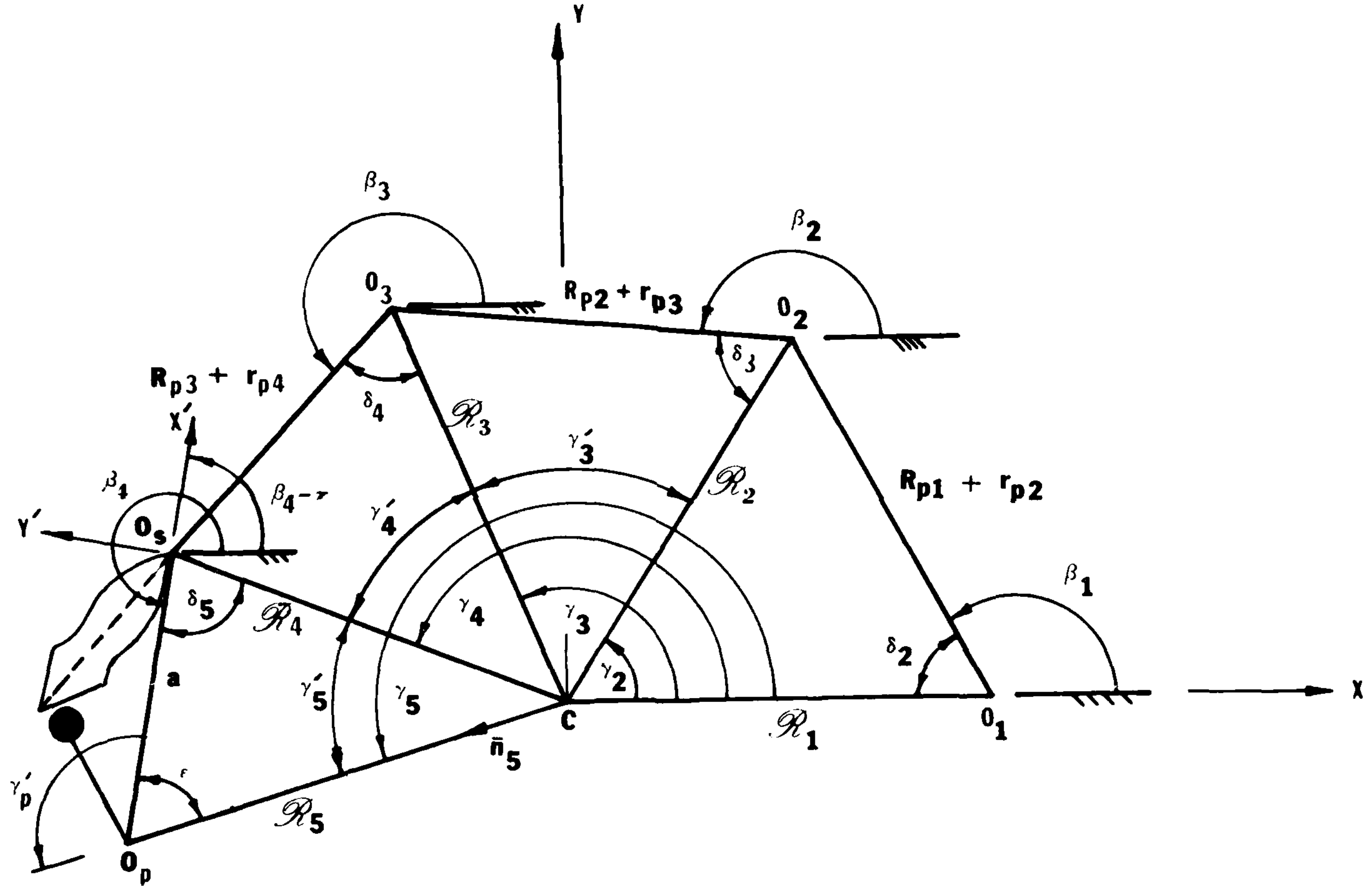

Figure A-3. Fuze body configuration no. 1 (three pass)

e following is obtained

$$\gamma_3 = \gamma_2 + \gamma_3' \tag{A-3}$$

lso from

$$\gamma_4' = \cos^{-1}\left[\frac{\mathcal{R}_3^2 + \mathcal{R}_4^2 - (R_{p3} + r_{p4})^2}{2\,\mathcal{R}_3\,\mathcal{R}_4}\right] \tag{A-4}$$

e following is obtained

$$\gamma_4 = \gamma_3 + \gamma_4' \tag{A-5}$$

ith a, the distance between the pallet and the escape wheel pivots, the following
s obtained

$$a^2 = \mathcal{R}_4^2 + \mathcal{R}_5^2 - 2\,\mathcal{R}_4\,\mathcal{R}_5 \cos\gamma_5' \tag{A-6}$$

hen,

$$\gamma_5' = \cos^{-1}\left[\frac{\mathcal{R}_4^2 + \mathcal{R}_5^2 - a^2}{2\,\mathcal{R}_4\,\mathcal{R}_5}\right] \tag{A-7}$$

nd

$$\gamma_5 = \gamma_4 + \gamma_5' \tag{A-8}$$

Angles δ_i

ince

$$\mathcal{R}_2^2 = (R_{p1} + r_{p2})^2 + \mathcal{R}_1^2 - 2(R_{p1} + r_{p2})\,\mathcal{R}_1 \cos\delta_2$$

$$\delta_2 = \cos^{-1}\left[\frac{(R_{p1} + r_{p2})^2 + \mathcal{R}_1^2 - \mathcal{R}_2^2}{2\,\mathcal{R}_1(R_{p1} + r_{p2})}\right] \tag{A-9}$$

imilarly,

$$\delta_3 = \cos^{-1}\left[\frac{(R_{p2} + r_{p3})^2 + \mathcal{R}_2^2 - \mathcal{R}_3^2}{2\,\mathcal{R}_2(R_{p2} + r_{p3})}\right] \tag{A-10}$$

and

$$\delta_4 = \cos^{-1}\left[\frac{(R_{p3} + r_{p4})^2 + \mathcal{R}_3^2 - \mathcal{R}_4^2}{2\,\mathcal{R}_3(R_{p3} + r_{p4})}\right] \tag{A-11}$$

Further, from

$$\mathcal{R}_5^2 = a^2 + \mathcal{R}_4^2 - 2a\,\mathcal{R}_4 \cos\delta_5 \tag{A-12}$$

the following is obtained

$$\delta_5 = \cos^{-1}\left[\frac{a^2 + \mathcal{R}_4^2 - \mathcal{R}_5^2}{2a\,\mathcal{R}_4}\right] \tag{A-13}$$

Angles β_i

With equation A-9

$$\beta_1 = \pi - \delta_2 \tag{A-14}$$

Further, with equations A-1 and A-10

$$\beta_2 = \gamma_2 + \pi - \delta_3 \tag{A-15}$$

With equations A-3 and A-11

$$\beta_3 = \gamma_3 + \pi - \delta_4 \tag{A-16}$$

Finally, this furnishes with equations A-5 and A-13:

$$\beta_4 = \gamma_4 + \pi - \delta_5 \tag{A-17}$$

Figure A-3 also shows that the angle γ_p' between the x'-axis and the unit vector $\bar{n}_5$ is given by:

$$\gamma_p' = \pi - \varepsilon \tag{A-18}$$

where

$$\varepsilon = \pi - \delta_5 - \gamma_5' \tag{A-19}$$

and therefore

$$\gamma_p' = \delta_5 + \gamma_5' \tag{A-20}$$

The unit vector $\bar{n}_5$ may now be expressed in terms of the primed coordinate system as follows:

$$\bar{n}_5 = \cos\, \gamma_p' \bar{i}' + \sin\, \gamma_p' \bar{j}' \tag{A-21}$$

Further, the unit vectors $\bar{i}'$ and $\bar{j}'$ are given in terms of the x-y system by:

$$\bar{i}' = \cos(\beta_4 - \pi)\bar{i} + \sin(\beta_4 - \pi)\bar{j}$$

$$\bar{i}' = -\cos\beta_4\bar{i} - \sin\beta_4\bar{j} \tag{A-22}$$

$$\bar{j}' = \bar{k}' \times \bar{i}' = -\sin(\beta_4 - \pi)\bar{i} + \cos(\beta_4 - \pi)\bar{j}$$

$$\bar{j}' = \sin\beta_4\bar{i} - \cos\beta_4\bar{j} \tag{A-23}$$

Fuze Body Configuration No. 2

Figure A-4 indicates the following relationships between the angles γ_i, δ_i, and β_i for fuze body configuration no. 2.

Angles γ_i

Since these angles are given in the clockwise direction with respect to the body-fixed x - axis, their values are negative. Thus, with the help of equation A-1:

$$\gamma_2 = -\cos^{-1}\left[\frac{\mathcal{R}_1^2 + \mathcal{R}_2^2 - (R_{p1} + r_{p2})^2}{2\,\mathcal{R}_1\mathcal{R}_2}\right] \tag{A-24}$$

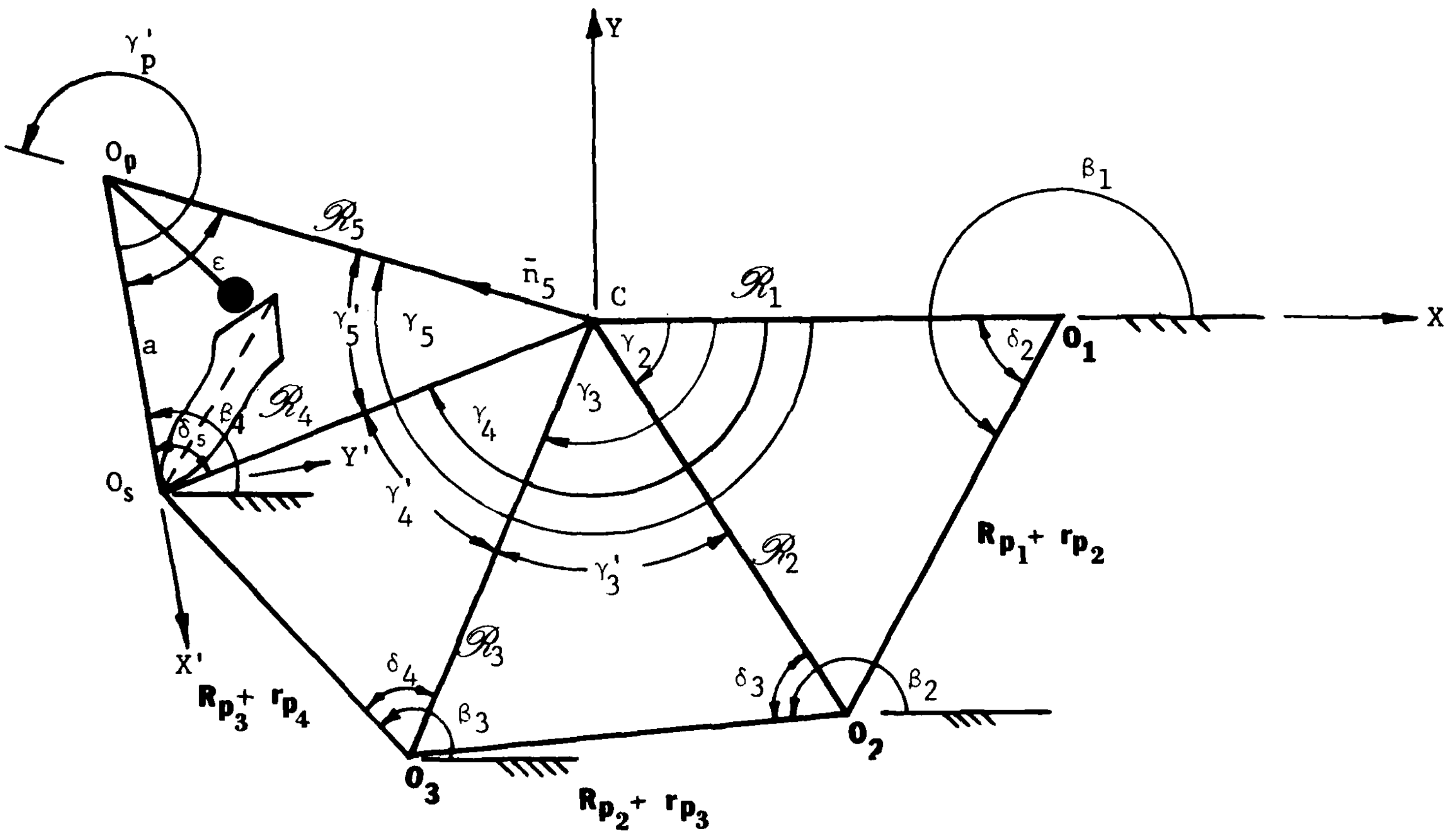

Figure A-4. Fuze body configuration no. 2 (three pass)

γ_3' is given by equation A-2, and with that γ_3 becomes

$$\gamma_3 = \gamma_2 - \gamma_3' \tag{A-25}$$

The negative sign for γ_3' is necessary in order to make γ_3 negative.

γ_4' is given by equation A-4. This leads to the following expression for γ_4 :

$$\gamma_4 = \gamma_3 - \gamma_4' \tag{A-26}$$

The angle γ_5' is again taken directly from equation A-7, and with that γ_5 becomes

$$\gamma_5 = \gamma_4 - \gamma_5' \tag{A-27}$$

Angles δ_i

The angles δ_2, δ_3, δ_4, and δ_5 may be taken directly from equations A-9, A-10, A-11, and A-13, respectively.

Angles β_i

With equation A-9

$$\beta_1 = \pi + \delta_2 \tag{A-28}$$

With equations A-10 and A-24

$$\beta_2 = \gamma_2 + \pi + \delta_3 \tag{A-29}$$

where the negative sign of equation A-24 for γ_2 is accounted for.

Similarly, with a negative sign of γ_3, one obtains with the help of equations A-11 and A-25:

$$\beta_3 = \gamma_3 + \pi + \delta_4 \tag{A-30}$$

Finally, with equations A-13 and A-24

$$\beta_4 = \gamma_4 + \pi + \delta_5 \tag{A-31}$$

According to figure A-4, the angle γ_p' between the positive x'-axis and the direction of unit vector $\bar{n}_5$ is now given by

$$\gamma_p' = \pi + \varepsilon \tag{A-32}$$

where

$$\varepsilon = \pi - \delta_5 - \gamma_5' \tag{A-33}$$

so that

$$\gamma_p' = 2\pi - \delta_5 - \gamma_5' \tag{A-34}$$

The unit vector $\bar{n}_5$, when expressed in the primed coordinate system, is again given by equation A-21, i.e.,

$$\bar{n}_5 = \cos\gamma_p'\bar{i}' + \sin\gamma_p'\bar{j}' \tag{A-35}$$

Further, the unit vectors $\bar{i}'$ and $\bar{j}'$ are given in terms of the x-y system by

$$\bar{i}' = \cos(\beta_4 + \pi)\bar{i} + \sin(\beta_4 + \pi)\bar{j}$$

$$\bar{i}' = -\cos\beta_4\bar{i} - \sin\beta_4\bar{j} \tag{A-36}$$

$$\bar{j}' = \bar{k}' \times \bar{i}' = -\sin(\beta_4 + \pi)\bar{i} + \cos(\beta_4 + \pi)\bar{j}$$

$$\bar{j}' = \sin\beta_4\bar{i} - \cos\beta_4\bar{j} \tag{A-37}$$

Common Computational Expressions for Both Configurations

In order to find common programming expressions for the angles of both configurations (with the exception of the angles γ_p' of equations A-20 and A-34), the following signum function s_6 is introduced, where

$$s_6 = +1 \text{ for configuration no. 1} \tag{A-38}$$

$$s_6 = -1 \text{ for configuration no. 2} \tag{A-39}$$

This leads to the following expressions:

according to equations A-1 and A-24

$$\gamma_2 = s_6 \cos^{-1}\left[\frac{\mathcal{R}_1^2 + \mathcal{R}_2^2 - (R_{p1} + r_{p2})^2}{2\,\mathcal{R}_1\,\mathcal{R}_2}\right] \tag{A-40}$$

according to equation A-2

$$\gamma_3' = \cos^{-1}\left[\frac{\mathcal{R}_2^2 + \mathcal{R}_3^2 - (R_{p2} + r_{p3})^2}{2\,\mathcal{R}_2\,\mathcal{R}_3}\right] \tag{A-41}$$

according to equations A-3 and A-25

$$\gamma_3 = \gamma_2 + s_6 \gamma_3' \tag{A-42}$$

according to equation A-4

$$\gamma_4' = \cos^{-1}\left[\frac{\mathcal{R}_3^2 + \mathcal{R}_4^2 - (R_{p3} + r_{p4})^2}{2\,\mathcal{R}_3\,\mathcal{R}_4}\right] \tag{A-43}$$

according to equations A-5 and A-26

$$\gamma_4 = \gamma_3 + s_6 \gamma_4' \tag{A-44}$$

according to equation A-7

$$\gamma_5' = \cos^{-1}\left[\frac{\mathcal{R}_4^2 + \mathcal{R}_5^2 - a^2}{2\,\mathcal{R}_4\,\mathcal{R}_5}\right] \tag{A-45}$$

according to equations A-8 and A-27

$$\gamma_5 = \gamma_4 + s_6\hat{\gamma}_5 \tag{A-46}$$

according to equations A-9, A-10, A-11, and A-13

$$\delta_2 = \cos^{-1}\left[\frac{(R_{p1} + r_{p2})^2 + \mathcal{R}_1^2 - \mathcal{R}_2^2}{2\,\mathcal{R}_1(R_{p1} + r_{p2})}\right] \tag{A-47}$$

$$\delta_3 = \cos^{-1}\left[\frac{(R_{p2} + r_{p3})^2 + \mathcal{R}_2^2 - \mathcal{R}_3^2}{2\,\mathcal{R}_2(R_{p2} + r_{p3})}\right] \tag{A-48}$$

$$\delta_4 = \cos^{-1}\left[\frac{(R_{p3} + r_{p4})^2 + \mathcal{R}_3^2 - \mathcal{R}_4^2}{2\,\mathcal{R}_3(R_{p3} + r_{p4})}\right] \tag{A-49}$$

$$\delta_5 = \cos^{-1}\left[\frac{a^2 + \mathcal{R}_4^2 - \mathcal{R}_5^2}{2a\,\mathcal{R}_4}\right] \tag{A-50}$$

according to equations A-14 and A-28

$$\beta_1 = \pi - s_6\delta_2 \tag{A-51}$$

according to equations A-15 and A-29

$$\beta_2 = \gamma_2 + \pi - s_6\delta_3 \tag{A-52}$$

according to equations A-16 and A-30

$$\beta_3 = \gamma_3 + \pi - s_6\delta_4 \tag{A-53}$$

according to equations A-17 and A-31

$$\beta_4 = \gamma_4 + \pi - s_6\delta_5 \tag{A-54}$$

The signum function s_6 will also be useful in conditional statements which distinguish between the γ_p''s of configuration no. 1 and 2 as given by equations A-20 and A-34.

Finally, according to equations A-22, A-23, A-36, and A-37, identical expressions may be used for both configurations when expressing the unit vectors of the primed coordinate systems in terms of the unprimed ones, i.e.,

$$\bar{i}' = -\cos\beta_4\bar{i} - \sin\beta_4\bar{j} \tag{A-55}$$

$$\bar{j}' = \sin\beta_4\bar{i} - \cos\beta_4\bar{j} \tag{A-56}$$

DYNAMICS OF THE PALLET IN COUPLED MOTION

While the following derivation for the dynamics of the pallet in coupled motion is illustrated with figures relating to configuration no. 1, all expressions are also applicable to configuration no. 2 as long as the appropriate sign for the signum function s_6 (eq A-38 and A-39), as well as the correct form of the angle γ_p' (eq A-20 and A-34) are used.[A-2]

As stated earlier, the dynamic analysis of the pallet is most conveniently performed in the primed coordinate system. The coefficient of friction at the pallet-escape wheel interface and at the pallet pivot has the designation μ_1.

With the spin ω of the fuze body constant, the acceleration of the center of mass of the pallet is given by figure A-5.

$$\begin{aligned}\bar{A}_{CP} &= -\omega^2 \mathcal{R}_5\bar{n}_5 - (\omega + \dot{\psi})^2 r_{CP}\left[\cos(\psi + \psi_C)\bar{i}' + \sin(\psi + \psi_C)\bar{j}'\right]\\ &\quad + \ddot{\psi} r_{CP}\left[-\sin(\psi + \psi_C)\bar{i}' + \cos(\psi + \psi_C)\bar{j}'\right]\end{aligned} \tag{A-57}$$

[A-2] This simple change in angles is all that is required since the relative rotation directions of the components are identical for both configurations, and therefore, force and moment expressions retain the same general form.

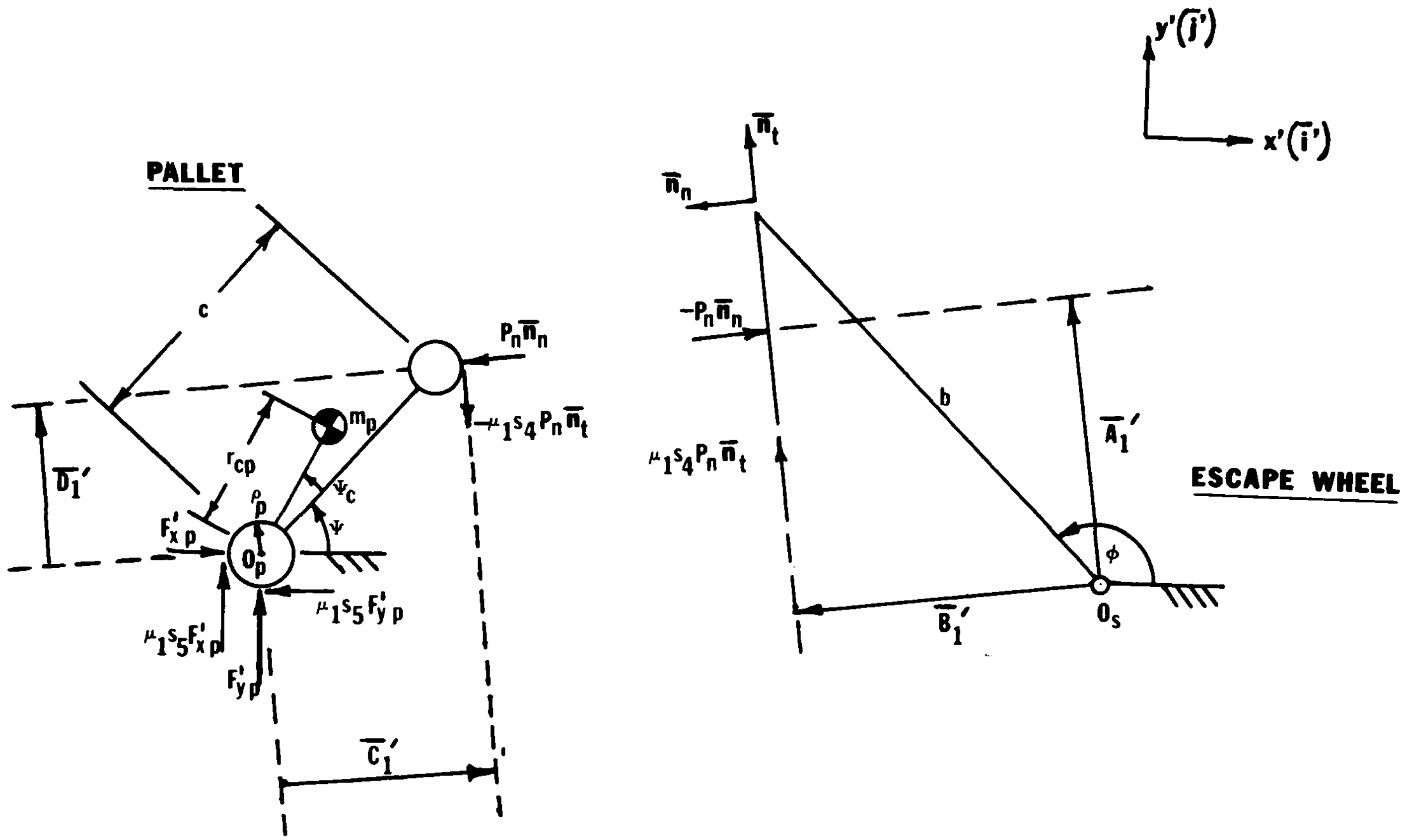

Figure A-5. Free body diagram of pallet with eccentric center of mass (given in x'-y' system, escape wheel shown for reference only)

With the above, and according to the free body diagram of figure A-5, substitution into Newton's law gives

$$P_n\bar{n}_n - \mu_1 s_4 P_n \bar{n}_t + F'_{xp}\bar{i}' - \mu_1 s_5 F'_{yp}\bar{i}' + F'_{yp}\bar{j}' + \mu_1 s_5 F'_{xp}\bar{j}'$$

$$= m_p \Big[-\omega^2 R_5 \bar{n}_5 - (\omega + \dot{\psi})^2 r_{CP}(\cos(\psi + \psi_C)\bar{i}' + \sin(\psi + \psi_C)\bar{j}')$$

$$+ \ddot{\psi} r_{CP}(-\sin(\psi + \psi_C)\bar{i}' + \cos(\psi + \psi_C)\bar{j}')\Big] \qquad \text{(A-58)}$$

The signum functions s_4 and s_5 assure the proper directions of the friction forces on the escape wheel - pallet interface as well as on the pallet shaft, regardless of the direction of pallet rotation. Thus,

$$s_4 = \frac{\dot{g}}{|\dot{g}|} \qquad \text{(A-59)}$$

(ref A-1, eq B-1) and

$$s_5 = \frac{\dot{\psi}}{|\dot{\psi}|} \qquad \text{(A-60)}$$

The unit vectors $\bar{n}_t$ and $\bar{n}_n$ are adapted from equations A-1 and A-2 (ref 1).

The moment equation of the pallet must be written with respect to the accelerated pivot O_p, i.e.,

$$\bar{M}_{O_p} = -\ddot{\bar{r}}_{O_p} \times m_p \bar{r}_{CP} + \dot{\bar{H}}_{O_p} \qquad \text{(A-61)}$$

where

$\bar{M}_{O_p}$ = sum of all external moments with respect to pivot O_p

$\ddot{\bar{r}}_{O_p}$ = absolute acceleration of point O_p

$\dot{\bar{H}}_{O_p}$ = time rate of change of angular momentum of the pallet with respect to point O_p.

Since the angular velocity $\bar{\omega}$ of the fuze body is constant equation A-61 takes the following form:

$$\bar{M}_{Op} = -(-\omega^2 \mathcal{R}_5 \bar{n}_5) \times m_p r_{CP}(\cos(\psi + \psi_C)\bar{i}' + \sin(\psi + \psi_C)\bar{j}') + I_p \ddot{\bar{\psi}} \tag{A-62}$$

Appropriate computations and substitution of all moments, according to figure A-5, furnish the final moment equation (the moment arms A_1, B_1, C_1, and D_1 of reference A-1 are now primed)

$$P_n(D_1' + C_1'\mu_1 s_4) - \rho_p \mu_1 s_5(\tilde{F}_{xp} + \tilde{F}_{yp}) = I_p \ddot{\psi} - m_p r_{CP} \mathcal{R}_5 \omega^2 \sin(\gamma_p' - \psi - \psi_C) \tag{A-63}$$

where

$$D_1' = c \cos(\phi - \alpha - \psi) \tag{A-64}$$

$$C_1' = -[r + c \sin(\phi - \alpha - \psi)] \tag{A-65}$$

As originally discussed in reference A-2, $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$ represent conservatively evaluated pivot force components which assure that the pivot friction moments are opposed to the rotation at all times. The following illustrates how this goal may be accomplished.

The pivot friction components F'_{xp} and F'_{yp} are first obtained from the following component expressions of equation A-58. Subsequently, they are transformed to become $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$, respectively.

$$-P_n \sin(\phi - \alpha) - \mu_1 s_4 P_n \cos(\phi - \alpha) + F'_{xp} - \mu_1 s_5 F'_{yp}$$

$$= m_p \left[-\omega^2 \mathcal{R}_5 \cos\gamma_p' - (\omega + \dot{\psi})^2 r_{CP} \cos(\psi + \psi_C) - \ddot{\psi} r_{CP} \sin(\psi + \psi_C)\right] \tag{A-66}$$

and

$$P_n \cos(\phi - \alpha) - \mu_1 s_4 P_n \sin(\phi - \alpha) + F'_{yp} + \mu_1 s_5 F'_{xp}$$

$$= m_p \left[-\omega^2 \mathcal{R}_5 \sin\gamma_p' - (\omega + \dot{\psi})^2 r_{CP} \sin(\psi + \psi_C) + \ddot{\psi} r_{CP} \cos(\psi + \psi_C)\right] \tag{A-67}$$

Simultaneous solution of equations A-66 and A-67 furnishes

$$\tilde{F}_{yp} = P_n A_1 + \omega^2 A_2 \pm 2\frac{\omega^2}{|\omega|}\dot{\psi} A_3 \pm \dot{\psi}^2 A_3 \pm \ddot{\psi} A_4 \tag{A-68}$$

$$\tilde{F}_{xp} = P_n A_5 + \omega^2 A_6 \pm 2\frac{\omega^2}{|\omega|}\dot{\psi} A_7 \pm \dot{\psi}^2 A_7 \pm \ddot{\psi} A_8 \tag{A-69}$$

where

$$A_1 = \left| \frac{\mu_1 (s_4 - s_5)\sin(\phi - \alpha) - (1 + s_4 s_5 \mu_1^2)\cos(\phi - \alpha)}{1 + \mu_1^2} \right| \tag{A-70}$$

$$A_2 = \left| \frac{m_p\left[\mathcal{R}_5(\sin\gamma_p' - \mu_1 s_5 \cos\gamma_p') + r_{CP}(\sin(\psi + \psi_C) - \mu_1 s_5 \cos(\psi + \psi_C))\right]}{1 + \mu_1^2} \right| \tag{A-71}$$

$$A_3 = \left| \frac{m_p r_{CP}\left[\sin(\psi + \psi_C) - \mu_1 s_5 \cos(\psi + \psi_C)\right]}{1 + \mu_1^2} \right| \tag{A-72}$$

$$A_4 = \left| \frac{m_p r_{CP}\left[\cos(\psi + \psi_C) + \mu_1 s_5 \sin(\psi + \psi_C)\right]}{1 + \mu_1^2} \right| \tag{A-73}$$

$$A_5 = \left| \frac{\mu_1 (s_4 - s_5)\cos(\phi - \alpha) + (1 + s_4 s_5 \mu_1^2)\sin(\phi - \alpha)}{1 + \mu_1^2} \right| \tag{A-74}$$

$$A_6 = \left| \frac{m_p\left[-\mathcal{R}_5(\cos\gamma_p' + \mu_1 s_5 \sin\gamma_p') - r_{CP}(\cos(\psi + \psi_C) + \mu_1 s_5 \sin(\psi + \psi_C))\right]}{1 + \mu_1^2} \right| \tag{A-75}$$

$$A_7 = \left| \frac{m_p r_{CP}\left[\cos(\psi + \psi_C) + \mu_1 s_5 \sin(\psi + \psi_C)\right]}{1 + \mu_1^2} \right| \tag{A-76}$$

$$A_8 = \left| \frac{m_p r_{CP}\left[\sin(\psi + \psi_C) - \mu_1 s_5 \cos(\psi + \psi_C)\right]}{1 + \mu_1^2} \right| \tag{A-77}$$

The factor $\omega^2/|\omega|$ is introduced in place of ω in order to make sure that the quantity is positive regardless of direction of spin. (This too, assures that the friction moments oppose rotation. The driving moment is proportional to ω^2, and therefore independent of spin direction.) To make the final decision concerning the signs of equations A-68 and A-69, these forces are substituted into moment equation A-63, and the influence of the direction of rotation on each of the resulting moment computations is explored:

$$P_n\left[D_1' + C_1'\mu_1 s_4 - \rho_p\mu_1 s_5(A_1 + A_5)\right] \pm \rho_p\mu_1 s_5\omega^2(A_2 + A_6)$$

$$\pm 2\rho_p\mu_1 s_5 \frac{\omega^2}{|\omega|}\dot{\psi}(A_3 + A_7) \pm \rho_p\mu_1 s_5\dot{\psi}^2(A_3 + A_7) \pm \rho_p\mu_1 s_5\ddot{\psi}(A_4 + A_8)$$

$$= I_p\ddot{\psi} - m_p r_{CP}\, \delta_5\omega^2 \sin(\gamma_p' - \psi - \psi_C) \qquad \text{(A-78)}$$

With s_5 positive for positive rotation, and vice versa, while all other parameters are positive at all times, the following moment components of equation A-78 must have negative signs during positive rotation:

$$-P_n\rho_p\mu_1 s_5(A_1 + A_5) \qquad \text{(A-79)}$$

$$-\rho_p\mu_1 s_5\omega^2(A_2 + A_6) \qquad \text{(A-80)}$$

$$-\rho_p\mu_1 s_5\dot{\psi}^2(A_3 + A_7) \qquad \text{(A-81)}$$

The sign of the term containing $\dot{\psi}$ is negative and is controlled by the sign of $\dot{\psi}$. Therefore, the signum operator s_5 is omitted and the term becomes

$$-2\rho_p\mu_1 \frac{\omega^2}{|\omega|}\dot{\psi}(A_3 + A_7) \qquad \text{(A-82)}$$

The choice of sign for the friction moment term in equation A-78, which is proportional to the angular acceleration $\ddot{\psi}$, is discussed in detail in appendix F. This work results in the computational rules of equations A-88 and A-89, which deal with the sign in the effective moment of inertia I_{PR}. (Note that the signum function s_5 function has now been omitted.)

With these considerations equation A-78 then becomes

$$P_n A_{18} - \omega^2 A_{19} - 2\frac{\omega^2}{|\omega|}\dot{\psi} A_{20} - \dot{\psi}^2 A_{21}$$

$$= I_{PR}\ddot{\psi} - m_p r_{CP}\, \Re_5 \omega^2 \left[\sin(\gamma_p' - \psi - \psi_C)\right] \quad \text{(A-83)}$$

ere[A-3]

$$A_{18} = D_1' + C_1' \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_5) \quad \text{(A-84)}$$

$$A_{19} = \rho_p \mu_1 s_5 (A_2 + A_6) \quad \text{(A-85)}$$

$$A_{20} = \rho_p \mu_1 (A_3 + A_7) \quad \text{(A-86)}$$

$$A_{21} = \rho_p \mu_1 s_5 (A_3 + A_7) \quad \text{(A-87)}$$

$$I_{PR} = I_p + A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have identical signs} \quad \text{(A-88)}$$

$$I_{PR} = I_p - A_{22},^{A-4} \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have opposite signs} \quad \text{(A-89)}$$

$$A_{22} = \rho_p \mu_1 (A_4 + A_8) \quad \text{(A-90)}$$

Equation A-83 is now used to find an expression for the contact force P_n. This ›ression will later make it possible to establish a single differential equation r the escapement in coupled motion. Thus,

$$= \frac{I_{PR}\ddot{\psi} + A_{21}\dot{\psi}^2 + 2\frac{\omega^2}{|\omega|} A_{20}\dot{\psi} + \omega^2 A_{19} - m_p r_{CP}\, \Re_5 \omega^2 \sin(\gamma_p' - \psi - \psi_C)}{A_{18}} \quad \text{(A-91)}$$

---

3 The parameters A_n are not sequential at this point. A_9 to A_{17} may be found in equations A-111 through A-116 and equations A-118 through A-120.

4 Care must be taken that $I_p - A_{22}$ does not become negative. If this occurs, I_{PR} must be set equal to zero. See footnote A-8 where the possible value of I_{PR} in the free motion equation of the pallet is discussed.

As in reference A-1 the variables $\dot{\psi}$ and $\ddot{\psi}$ are now expressed in terms of $\dot{\phi}$ and $\ddot{\phi}$ the escape wheel variables (ref A-1, eq A-15 through A-18 and B-6)

$$\ddot{\psi} = U\ddot{\phi} + V\dot{\phi}^2 \tag{A-92}$$

and

$$\dot{\psi} = Z\dot{\phi} \text{ (Z is not defined in ref A-1)} \tag{A-93}$$

where

$$Z = \frac{1}{c\cos\psi}\left[Q + \frac{aP}{S}\sin(\phi - \alpha)\right] \tag{A-94}$$

Equation A-91 then becomes

$$P_n = \frac{1}{A_{18}}\left[I_{PR}U\ddot{\phi} + (A_{21}Z^2 + I_{PR}V)\dot{\phi}^2 + 2\frac{\omega^2}{|\omega|}A_{20}Z\dot{\phi}\right.$$

$$\left. + \omega^2 A_{19} - m_p r_{CP}\mathcal{R}_5\omega^2\sin(\gamma_p' - \psi - \psi_C)\right] \tag{A-95}$$

DYNAMICS OF ESCAPE WHEEL IN COUPLED MOTION (ESCAPE WHEEL INCORPORATES PINION NO. 4)

While figure A-6 shows a free body diagram of the escape wheel and pinion no. 4 of configuration no. 1, the following derivations hold for both configurations as long as the appropriate signum function s_6 is chosen. The pivot forces F_{x4} and F_{y4} as well as forces F_{34} and T_4 are now defined in the general x-y system. This makes it necessary to give the unit vectors $\bar{n}_t$ and $\bar{n}_n$ in terms of the x-y system.

From equations A-1 and A-2, reference A-1 (and using x'-y' coordinates)

$$\bar{n}_t = \cos(\phi - \alpha)\,\bar{i}' + \sin(\phi - \alpha)\,\bar{j}' \tag{A-96}$$

$$\bar{n}_n = -\sin(\phi - \alpha)\,\bar{i}' + \cos(\phi - \alpha)\,\bar{j}' \tag{A-97}$$

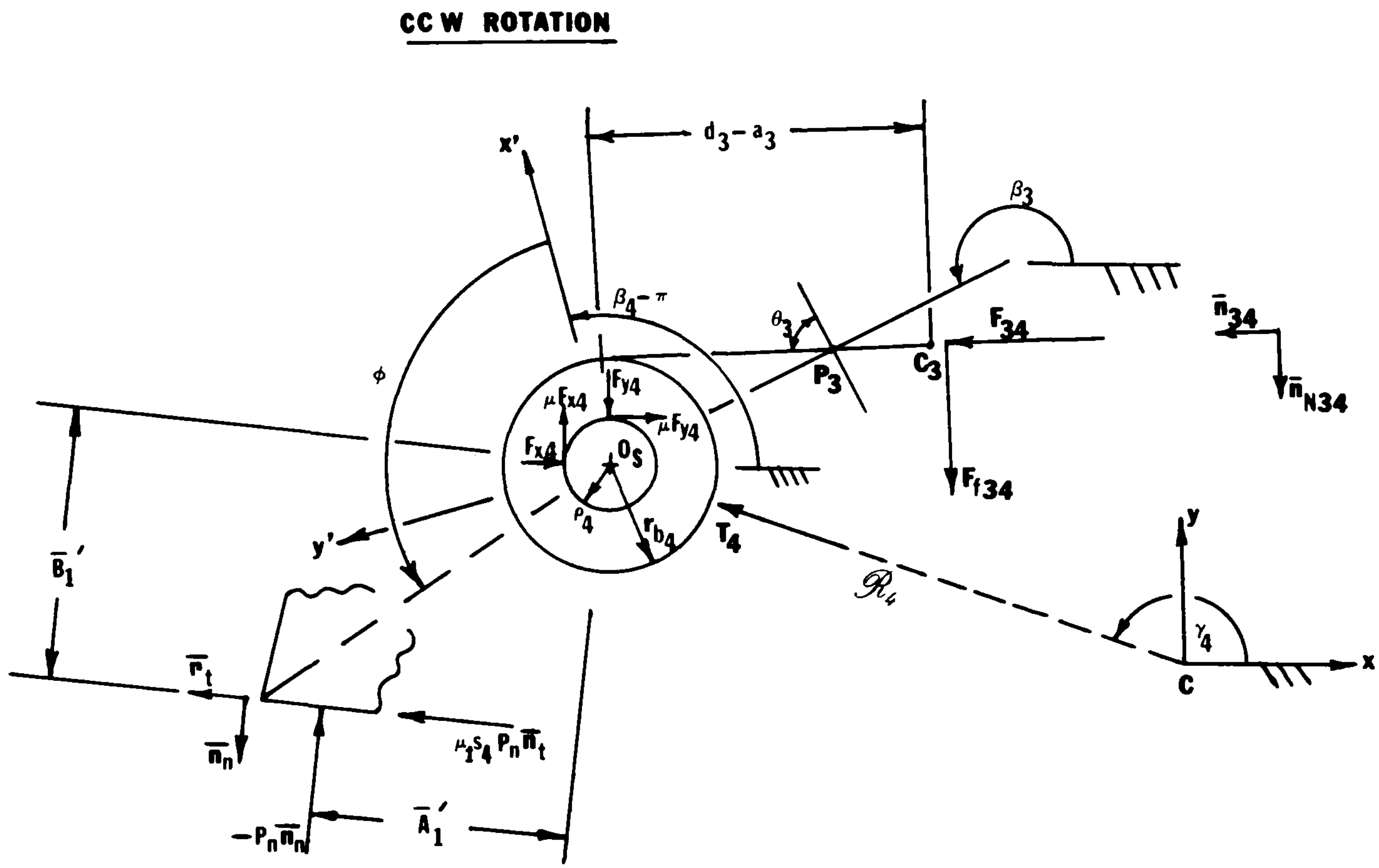

Figure A-6. Free body diagram of escape wheel and pinion 4

Equations A-55 and A-56, which hold regardless of configurations, are used for the following transformed expressions:

$$\bar{n}_t = -\cos(\phi - \alpha + \beta_4)\ \bar{i} - \sin(\phi - \alpha + \beta_4)\ \bar{j} \tag{A-98}$$

and

$$\bar{n}_n = \sin(\phi - \alpha + \beta_4)\ \bar{i} - \cos(\phi - \alpha + \beta_4)\ \bar{j} \tag{A-99}$$

The expressions for the unit vectors $\bar{n}_{34}$ and $\bar{n}_{N34}$, as used in the analysis of pinion no. 4 in reference A-2, section A-1a, are of further interest

$$\bar{n}_{34} = \sin(\beta_3 + \theta_3)\ \bar{i} - \cos(\beta_3 + \theta_3)\ \bar{j} \tag{A-100}$$

and

$$\bar{n}_{N34} = \cos\ (\beta_3 + \theta_3)\ \bar{i} + \sin(\beta_3 + \theta_3)\ \bar{j} \tag{A-101}$$

Using the concept of the D'Alembert force

$$\bar{T}_4 = m_4\ \Re_4\ \omega^2(\cos\gamma_4\ \bar{i} + \sin\gamma_4\ \bar{j}), \tag{A-102}$$

the force equation of the escape wheel assembly becomes for counterclockwise rotation[A-5] (ref A-2, eq A-35)

$$-P_n\ \bar{n}_n + \mu_1 s_4 P_n \bar{n}_t + F_{34}\bar{n}_{34} + \mu s_3 F_{34}\bar{n}_{N34} + \bar{T}_4 + F_{x4}\bar{i} + \mu F_{y4}\bar{i}$$

$$+ \mu F_{x4}\bar{j} - F_{y4}\bar{j} = 0 \tag{A-103}$$

Note that the coefficient of friction μ is now used for all pivots and gear tooth contacts [A-6] of the remainder of the mechanism train.

[A-5] See appendix F for description of motion reversal, i.e., clockwise escape wheel rotation. This may occur after severe impacts.

[A-6] The signum functions s_1, s_2, and s_3 are defined in reference A-2 in connection with the tooth contact friction of the various meshes.

The moment equation of the escape wheel for counterclockwise rotation is written with the help of figure A-6

$$-P_n(A_1' + B_1'\mu_1 s_4) - \mu\rho_4(\tilde{F}_{x4} + \tilde{F}_{y4}) + r_{b4}F_{34} - \mu s_3(d_3 - a_3)\ F_{34} = I_4\ddot{\phi} \qquad \text{(A-104)}$$

where

$$A_1' = b\ \cos\alpha + g \qquad \text{(A-105)}$$

$$B_1' = b\ \sin\alpha \qquad \text{(A-106)}$$

The pivot forces $\tilde{F}_{x4}$ and $\tilde{F}_{y4}$ are treated again in the manner discussed earlier. They are obtained from the component expressions of equation A-103, i.e.,

$$-P_n\sin(\phi-\alpha+\beta_4) - s_4\mu_1P_n\cos(\phi-\alpha+\beta_4) + F_{34}\sin(\beta_3+\theta_3)$$

$$+ \mu s_3F_{34}\cos(\beta_3+\theta_3) + T_4\cos\gamma_4 + F_{x4} + \mu F_{y4} = 0 \qquad \text{(A-107)}$$

and

$$P_n\cos(\phi-\alpha+\beta_4) - s_4\mu_1P_n\sin(\phi-\alpha+\beta_4) - F_{34}\cos(\beta_3+\theta_3)$$

$$+ \mu s_3F_{34}\sin(\beta_3+\theta_3) + T_4\sin\gamma_4 - F_{y4} + \mu F_{x4} = 0 \qquad \text{(A-108)}$$

Simultaneous solution of equations A-107 and A-108 gives

$$\tilde{F}_{y4} = P_n\ A_9 + F_{34}\ A_{10} + T_4\ A_{11} \qquad \text{(A-109)}$$

$$\tilde{F}_{x4} = P_n\ A_{12} + F_{34}\ A_{13} + T_4\ A_{14} \qquad \text{(A-110)}$$

where

$$A_9 = \left| \frac{-(\mu_1 s_4 - \mu)\sin(\phi - \alpha + \beta_4) + (1 + \mu\mu_1 s_4)\cos(\phi - \alpha + \beta_4)}{1 + \mu^2} \right| \tag{A-111}$$

$$A_{10} = \left| \frac{-\mu(1 - s_3)\sin(\beta_3 + \theta_3) - (1 + \mu^2 s_3)\cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \tag{A-112}$$

$$A_{11} = \left| \frac{\sin\gamma_4 - \mu\cos\gamma_4}{1 + \mu^2} \right| \tag{A-113}$$

$$A_{12} = \left| \frac{(1 + \mu_1\mu s_4)\sin(\phi - \alpha + \beta_4) + (s_4\mu_1 - \mu)\cos(\phi - \alpha + \beta_4)}{1 + \mu^2} \right| \tag{A-114}$$

$$A_{13} = \left| \frac{-(1 + \mu^2 s_3)\sin(\beta_3 + \theta_3) + \mu(1 - s_3)\cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \tag{A-115}$$

$$A_{14} = \left| \frac{-\cos\gamma_4 - \mu\sin\gamma_4}{1 + \mu^2} \right| \tag{A-116}$$

Substitution of the pivot force component expressions, with the indicated signs, into the moment equation A-104 will furnish the correct pivot friction moments. The resulting expression is then solved for the contact force P_n

$$P_n = \frac{-I_4\ddot{\phi} + F_{34}A_{15} - T_4 A_{16}}{A_{17}} \tag{A-117}$$

where

$$A_{15} = r_{b4} - \mu\left[s_3(d_3 - a_3) + \rho_4(A_{10} + A_{13})\right] \tag{A-118}$$

$$A_{16} = \mu\rho_4(A_{11} + A_{14}) \tag{A-119}$$

$$A_{17} = A_1' + \mu_1 s_4 B_1' + \mu\rho_4(A_9 + A_{12}) \tag{A-120}$$

COMBINED COUPLED MOTION DIFFERENTIAL EQUATION FOR ESCAPE WHEEL AND PALLET (APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

To obtain a combined coupled motion differential equation for the pallet and escape wheel in terms of the escape wheel angle ϕ, equations A-95 and A-117, both for the contact force P_n are set equal to each other. This furnishes

$$\left[I_4A_{18} + I_{PR}A_{17}U\right]\ddot{\phi} + \left[I_{PR}A_{17}V + A_{17}A_{21}Z^2\right]\dot{\phi}^2 + 2\frac{\omega^2}{|\omega|}A_{17}A_{20}Z\dot{\phi}$$

$$= A_{15}A_{18}F_{34} - A_{16}A_{18}T_4 - A_{17}\omega^2\left[A_{19} - m_p r_{CP}\,\mathcal{R}_5\sin(\gamma_P' - \psi - \psi_C)\right] \qquad \text{(A-121)}$$

To complete the system differential equation, it is necessary to find an expression for the contact force F_{34} in the above. This will be accomplished by combining the appropriate differential equations for gear and pinion no. 2 and 3 and for the rotor.

DYNAMICS OF ROTOR (GEAR NO. 1) (APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

A free body diagram of the rotor for configuration no. 1 is shown in figure A-7. The acceleration $\bar{A}_{CR}$ of its center of mass, with constant spin velocity $\bar{\omega}$, is given by

$$\bar{A}_{CR} = -\omega^2\,\mathcal{R}_1\bar{i} - (\omega+\dot{\phi}_1)^2 r_{C1}\left[\cos(\phi_{1C}+\phi_1)\bar{i} + \sin(\phi_{1C}+\phi_1)\bar{j}\right]$$

$$+ \ddot{\phi}_1 r_{C1}\left[-\sin(\phi_{1C}+\phi_1)\bar{i} + \cos(\phi_{1C}+\phi_1)\bar{j}\right] \qquad \text{(A-122)}$$

Since the motion of the rotor must be expressed in terms of the escape wheel variables, the following transformations are now introduced:

$$\dot{\phi}_1 = N_{41}\,\dot{\phi} \qquad \text{(A-123)}$$

$$\ddot{\phi}_1 = N_{41}\,\ddot{\phi} \qquad \text{(A-124)}$$

where

$$N_{41} = -\frac{N_{P4}}{N_{G3}}\frac{N_{P3}}{N_{G2}}\frac{N_{P2}}{N_{G1}} \qquad \text{(A-125)}$$

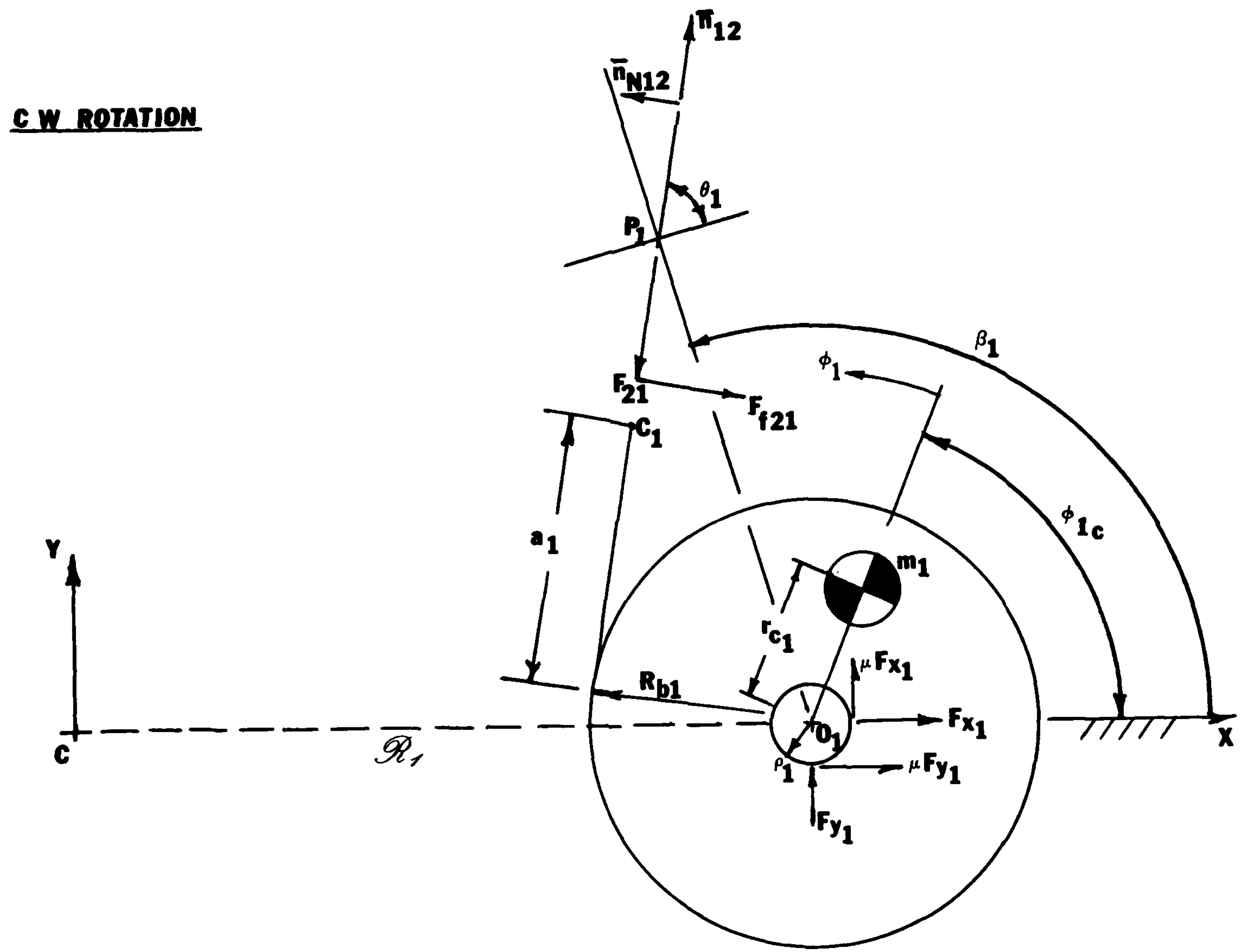

Figure A-7. Free body diagram of rotor (gear no. 1)

The rotor angle $\phi_{1C} + \phi_1$, is expressed as follows:

$$\phi_{1C} + \phi_1 = \phi_{1C} + N_{41}\ \phi_T \tag{A-126}$$

where ϕ_T represents the total rotation of the escape wheel from the inception of motion. (The section on Geometry of Fuze Body Configuration describes the manner in which ϕ_T is obtained as a function of the instantaneous angle ϕ.)

Equation A-122 then becomes

$$\bar{A}_{CR} = -\omega^2\ \beta_1\bar{i} - (\omega + N_{41}\dot{\phi})^2\ r_{C1}\ [\cos(\phi_{1C} + N_{41}\phi_T)\bar{i} + \sin(\phi_{1C} + N_{41}\phi_T)\bar{j}\,]$$

$$+ N_{41}\ddot{\phi}\ r_{C1}[-\sin(\phi_{1C} + N_{41}\phi_T)\bar{i} + \cos(\phi_{1C} + N_{41}\phi_T)\bar{j}\,] \tag{A-127}$$

Newton's force equation is now written for clockwise rotation of the rotor with the help of equation A-127 and the free body diagram of figure A-7:[A-7]

$$-F_{12}\bar{n}_{12} - \mu\, s_1 F_{12}\bar{n}_{N12} - F_{x1}\bar{i} + \mu F_{y1}\bar{i} + F_{y1}\bar{j} + \mu F_{x1}\bar{j} = m_1\bar{A}_{CR} \tag{A-128}$$

where

$$\bar{n}_{12} = \sin(\beta_1 + \theta_1)\bar{i} - \cos(\beta_1 + \theta_1)\bar{j} \tag{A-129}$$

$$\bar{n}_{N12} = \cos(\beta_1 + \theta_1)\bar{i} + \sin(\beta_1 + \theta_1)\bar{j} \tag{A-130}$$

(ref A-2, eq A-78 and A-79)

Further, in figure A-7

$$\bar{F}_{21} = -F_{12}\bar{n}_{12} \tag{A-131}$$

and

$$\bar{F}_{f21} = -\ \mu\, s_1\ F_{12}\ \bar{n}_{N12} \tag{A-132}$$

(ref A-2, eq A-103 and A-104)

[A-7] Description of motion reversal, appendix F.

The moment equation must be written in the manner of equation A-61, with respect to the accelerated point 0_1. The pivot reactions $\tilde{F}_{x1}$ and $\tilde{F}_{y1}$ are treated so that the associated friction moments retard the clockwise rotation of the rotor. This leads to

$$R_{b1}F_{12}\bar{k} - \mu s_1 a_1 F_{12}\bar{k} + \mu\rho_1(\tilde{F}_{x1}+F_{y1})\bar{k}$$

$$= -(-\omega^2 \mathcal{R}_1\bar{i}) \times m_1 r_{C1} \left[\cos(\phi_{1C}+N_{41}\phi_T)\bar{i} + \sin(\phi_{1C}+N_{41}\phi_T)\bar{j}\right]$$

$$+ I_1 N_{41}\ddot{\phi}\bar{k} \qquad \text{(A-133)}$$

This becomes

$$R_{b1}F_{12} - \mu s_1 a_1 F_{12} + \mu\rho_1(\tilde{F}_{x1} + \tilde{F}_{y1})$$

$$= m_1\omega^2 \mathcal{R}_1 r_{C1}\sin(\phi_{1C} + N_{41}\phi_T) + I_1 N_{41}\ddot{\phi} \qquad \text{(A-134)}$$

The forces $\tilde{F}_{x1}$ and $\tilde{F}_{y1}$ are obtained from the simultaneous solution of the following component expressions of equation A-128:

$$-F_{12}\sin(\beta_1+\theta_1) - \mu s_1 F_{12}\cos(\beta_1+\theta_1) - F_{x1} + \mu F_{y1}$$

$$= m_1 \left[-\omega^2 \mathcal{R}_1 - (\omega+N_{41}\dot{\phi})^2 r_{C1}\cos(\phi_{1C}+N_{41}\phi_T) - N_{41}\ddot{\phi} r_{C1}\sin(\phi_{1C}+N_{41}\phi_T)\right] \qquad \text{(A-135)}$$

$$F_{12}\cos(\beta_1+\theta_1) - \mu s_1 F_{12}\sin(\beta_1+\theta_1) + F_{y1} + \mu F_{x1}$$

$$= m_1 \left[-(\omega+N_{41}\dot{\phi})^2 r_{C1}\sin(\phi_{1C}+N_{41}\phi_T) + N_{41}\ddot{\phi} r_{C1}\cos(\phi_{1C}+N_{41}\phi_T)\right] \qquad \text{(A-136)}$$

Simultaneous solution of the above gives

$$\tilde{F}_{y1} = F_{12}A_{23} \pm \omega^2 A_{24} \pm \frac{2\omega^2}{|\omega|}N_{41}\dot{\phi}A_{25} \pm (N_{41}\dot{\phi})^2 A_{25} \pm N_{41}\ddot{\phi}A_{26} \qquad \text{(A-137)}$$

and

$$\tilde{F}_{x1} = F_{12}A_{27} \pm \omega^2 A_{28} \pm 2\frac{\omega^2}{|\omega|}N_{41}\dot{\phi}A_{29} \pm (N_{41}\dot{\phi})^2 A_{29} \pm N_{41}\ddot{\phi}A_{30} \qquad \text{(A-138)}$$

where

$$A_{23} = \left| \frac{\mu(1+s_1)\sin(\beta_1+\theta_1) - (1-\mu^2 s_1)\cos(\beta_1+\theta_1)}{1+\mu^2} \right| \tag{A-139}$$

$$A_{24} = \left| \frac{m_1[\mu \mathcal{R}_1 + r_{C1}(\mu\cos(\phi_{1C}+N_{41}\phi_T)+\sin(\phi_{1C}+N_{41}\phi_T))]}{1+\mu^2} \right| \tag{A-140}$$

$$A_{25} = \left| \frac{m_1 r_{C1}[\mu\cos(\phi_{1C}+N_{41}\phi_T)+\sin(\phi_{1C}+N_{41}\phi_T)]}{1+\mu^2} \right| \tag{A-141}$$

$$A_{26} = \left| \frac{m_1 r_{C1}[\cos(\phi_{1C}+N_{41}\phi_T)-\mu\sin(\phi_{1C}+N_{41}\phi_T)]}{1+\mu^2} \right| \tag{A-142}$$

and

$$A_{27} = \left| \frac{(1-\mu^2 s_1)\sin(\beta_1+\theta_1) + \mu(1+s_1)\cos(\beta_1+\theta_1)}{1+\mu^2} \right| \tag{A-143}$$

$$A_{28} = \left| \frac{m_1[\mathcal{R}_1 + r_{C1}(\cos(\phi_{1C}+N_{41}\phi_T) - \mu\sin(\phi_{1C}+N_{41}\phi_T))]}{1+\mu^2} \right| \tag{A-144}$$

$$A_{29} = \left| \frac{m_1 r_{C1}[\cos(\phi_{1C}+N_{41}\phi_T) - \mu\sin(\phi_{1C}+N_{41}\phi_T)]}{1+\mu^2} \right| \tag{A-145}$$

$$A_{30} = \left| \frac{m_1 r_{C1}[\sin(\phi_{1C}+N_{41}\phi_T) + \mu\cos(\phi_{1C}+N_{41}\phi_T)]}{1+\mu^2} \right| \tag{A-146}$$

Equations A-137 and A-138 are now substituted into the moment equation A-134 as follows:

$$R_{b1}F_{12} - \mu s_1 a_1 F_{12} + \mu\rho_1\Big[F_{12}(A_{23}+A_{27}) \pm \omega^2(A_{24}+A_{28})$$

$$\pm\, 2\frac{\omega^2}{|\omega|} N_{41}\dot{\phi}(A_{25}+A_{29}) \pm (N_{41}\dot{\phi})^2(A_{25}+A_{29}) \pm N_{41}\ddot{\phi}(A_{26}+A_{30})\Big]$$

$$= m_1\omega^2 \mathcal{R}_1 r_{C1}\sin(\phi_{1C}+N_{41}\phi_T) + I_1 N_{41}\ddot{\phi} \qquad \text{(A-147)}$$

In order to have the pivot friction moments positive for clockwise rotation, the following terms must be positive:

$$\mu\ \rho_1\ F_{12}\ (A_{23} + A_{27})$$

$$\mu\ \rho_1\omega^2\ (A_{24} + A_{28})$$

$$\mu\ \rho_1\ (N_{41}\dot{\phi})^2\ (A_{25} + A_{29})$$

The term

$$2\ \mu\ \rho_1 \frac{\omega^2}{|\omega|} N_{41}\dot{\phi}(A_{25}+A_{29})$$

must also be positive for clockwise rotation of the rotor. This can only be accomplished by making the term negative since N_{41} is negative. To avoid the use of μ as a signum function, as required for motion reversal according to appendix E, its value is made absolute. Possible motion reversal is then only affected by the sign of $\dot{\phi}$, the angular velocity of the escape wheel, which is normally positive. Then the resulting term has the following form:

$$-2\,|\mu|\,\rho_1\frac{\omega^2}{|\omega|} N_{41}\dot{\phi}\ (A_{25} + A_{29})$$

In order to determine the sign of the pivot friction moment which is proportional to the angular acceleration $\ddot{\phi}$ of the escape wheel in equation A-147, the ideas presented in appendix F are used. To be able to do this let the value of the

coefficient of friction of this term become absolute, so that it ceases to serve as a directional signum function in the sense of appendix E. Further let the expression be changed, for the time being, so that it becomes a function of the rotor acceleration $\ddot{\phi}_1$. With the above and in the sense of equation F-2, appendix F, the absolute value of this friction moment M_{AA} may be expressed as

$$M_{AA} = |\mu|\rho_1 (A_{26} + A_{30})\ \ddot{\phi}_1$$

From this point on one may use the reasoning of appendix F directly, keeping in mind that $|\mu|\rho_1(A_{26} + A_{30})$ and $\ddot{\phi}_1$ are now used instead of A_{22} and $\ddot{\psi}$, respectively.

As for the four cases in appendix F, the effective moment of inertia I_{1R} takes two forms:

$$I_{1R} = I_1 + |\mu|\rho_1 (A_{26} + A_{30}),\ \text{when } \dot{\phi}_1 \text{ and } \ddot{\phi}_1 \text{ have the same sign,}$$

and

$$I_{1R} = I_1 - |\mu|\rho_1 (A_{26} + A_{30}),\ \text{when } \dot{\phi}_1 \text{ and } \ddot{\phi}_1 \text{ have opposite signs}$$

Equation A-147 gives all relevant expressions in terms of the escape wheel variables $\ddot{\phi}$ and $\dot{\phi}$. Since they both are proportional to $\ddot{\phi}_1$ and $\dot{\phi}_1$ by the identical gear ratio N_{41} (or in the case of the two pass train by way of N_{31}), one may readily extend the above computational rule to the escape wheel variables. This is reflected by equations A-155 and A-156.

The above considerations give the moment equation A-147 the following form:

$$F_{12}\left[R_{b1} - \mu s_1 a_1 + \mu\rho_1(A_{23}+A_{27})\right] + \omega^2 \rho_1\mu(A_{24}+A_{28})$$

$$- 2|\mu|\rho_1 \frac{\omega^2}{|\omega|} N_{41}\dot{\phi}(A_{25}+A_{29}) + \mu\rho_1(N_{41}\dot{\phi})^2 (A_{25}+A_{29})$$

$$= m_1 r_{C1}\, \mathcal{R}_1\omega^2 \sin(\phi_{1C}+N_{41}\phi_T) + (I_1 + \mu\rho_1(A_{26}+A_{30}))N_{41}\ddot{\phi} \qquad \text{(A-148)}$$

Finally the above expression is solved for F_{12}

$$F_{12} = \frac{-A_{32} + N_{41} A_{33} \dot{\phi} - A_{34}(N_{41}\dot{\phi})^2 + A_{35} \sin(\phi_{1C} + N_{41}\phi_T) + I_{1R} N_{41} \ddot{\phi}}{A_{31}} \tag{A-149}$$

where

$$A_{31} = R_{b1} - \mu s_1 a_1 + \mu \rho_1 (A_{23} + A_{27}) \tag{A-150}$$

$$A_{32} = \omega^2 \rho_1 \mu (A_{24} + A_{28}) \tag{A-151}$$

$$A_{33} = 2 \frac{\omega^2}{|\omega|} |\mu| \rho_1 (A_{25} + A_{29}) \tag{A-152}$$

$$A_{34} = \mu \rho_1 (A_{25} + A_{29}) \tag{A-153}$$

$$A_{35} = m_1 \mathcal{R}_1 r_{C1} \omega^2 \tag{A-154}$$

$$I_{1R} = I_1 + |\mu| \rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have the same signs} \tag{A-155}$$

$$I_{1R} = I_1 - |\mu| \rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have opposite signs} \tag{A-156}$$

DYNAMICS OF GEAR AND PINION SET NO. 3
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

The moment equation of gear and pinion no. 3 may be taken from reference A-2 if its right hand side is set equal to $I_3 \ddot{\phi}_3$ rather than to zero. (The dynamic force equation was already satisfied by the inclusion of the inertia force T_3.) Thus, with the help of equation A-65, reference A-2, and letting

$$\ddot{\phi}_3 = N_{43} \ddot{\phi} \tag{A-157}$$

ı

$$N_{43} = - \frac{N_{P4}}{N_{G3}} \qquad \text{(A-158)}$$

following expression is obtained

$$\begin{aligned} {}_3F_{34} - \mu s_3 a_3 F_{34} - r_{b3} F_{23} + \mu s_2(d_2 - a_2) F_{23} \\ + \mu\rho_3\left[F_{23}(A_{36} + A_{39}) + T_3(A_{37} + A_{40}) + F_{34}(A_{38} + A_{41})\right] \\ = I_3 N_{43}\ddot{\phi} \end{aligned} \qquad \text{(A-159)}$$

re

$${}_6 = \left| \frac{(1 + \mu^2 s_2)\cos(\beta_2 - \theta_2) + \mu(s_2 - 1)\sin(\beta_2 - \theta_2)}{1 + \mu^2} \right| \qquad \text{(A-160)}$$

$${}_7 = \left| \frac{\sin\gamma_3 + \mu\cos\gamma_3}{1 + \mu^2} \right| \qquad \text{(A-161)}$$

$${}_8 = \left| \frac{(1 - \mu^2 s_3)\cos(\beta_3 + \theta_3) - \mu(1 + s_3)\sin(\beta_3 + \theta_3)}{1 + \mu^2} \right| \qquad \text{(A-162)}$$

$${}_9 = \left| \frac{(1 + \mu^2 s_2)\sin(\beta_2 - \theta_2) + \mu(1 - s_2)\cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \qquad \text{(A-163)}$$

$${}_0 = \left| \frac{\mu\sin\gamma_3 - \cos\gamma_3}{1 + \mu^2} \right| \qquad \text{(A-164)}$$

$${}_1 = \left| \frac{(1 - \mu^2 s_3)\sin(\beta_3 + \theta_3) + \mu(1 + s_3)\cos(\beta_3 + \theta_3)}{1 + \mu^2} \right| \qquad \text{(A-165)}$$

If equation A-159 is solved for F_{23}, the following is obtained:

$$F_{23} = \frac{F_{34} A_{42} + T_3 A_{43} - I_3 N_{43} \ddot{\phi}}{A_{44}} \tag{A-166}$$

where

$$A_{42} = R_{b3} - \mu\left[s_3 a_3 - \rho_3(A_{38} + A_{41})\right] \tag{A-167}$$

$$A_{43} = \mu\rho_3(A_{37} + A_{40}) \tag{A-168}$$

$$A_{44} = r_{b3} - \mu\left[s_2(d_2 - a_2) + \rho_3(A_{36} + A_{39})\right] \tag{A-169}$$

DYNAMICS OF GEAR AND PINION SET NO. 2
(APPLICATION TO BOTH CONFIGURATIONS WITH PROPER s_6)

The moment equation of gear and pinion set no. 2 may also be taken from reference A-2 with the provision that its right hand side is set equal to $I_2\ddot{\phi}$, rather than equal to zero. (Again, the force equation was already satisfied by the inertia force T_2.)

With the help of equation A-92, reference A-2, and letting

$$\ddot{\phi}_2 = N_{42} \ddot{\phi} \tag{A-170}$$

where

$$N_{42} = -\frac{N_{P4} N_{P3}}{N_{G3} N_{G2}} \tag{A-171}$$

the following is obtained:

$$-R_{b2}F_{23} + \mu s_2 a_2 F_{23} + r_{b2}F_{12} - \mu s_1(d_1 - a_1)F_{12}$$

$$-\mu\rho_2\left[F_{12}(A_{45}+A_{48}) + T_2(A_{46}+A_{49}) + F_{23}(A_{47}+A_{50})\right] = I_2 N_{42}\ddot{\phi} \tag{A-172}$$

where

$$A_{45} = \left| \frac{\mu(1 - s_1)\sin(\beta_1 + \theta_1) + (1 + \mu^2 s_1)\cos(\beta_1 + \theta_1)}{1 + \mu^2} \right| \tag{A-173}$$

$$A_{46} = \left| \frac{\sin\gamma_2 - \mu\cos\gamma_2}{1 + \mu^2} \right| \tag{A-174}$$

$$A_{47} = \left| \frac{\mu(1 + s_2)\sin(\beta_2 - \theta_2) + (1 - \mu^2 s_2)\cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \tag{A-175}$$

$$A_{48} = \left| \frac{\mu(1 - s_1)\cos(\beta_1 + \theta_1) - (1 + \mu^2 s_1)\sin(\beta_1 + \theta_1)}{1 + \mu^2} \right| \tag{A-176}$$

$$A_{49} = \left| \frac{\mu\sin\gamma_2 + \cos\gamma_2}{1 + \mu^2} \right| \tag{A-177}$$

$$A_{50} = \left| \frac{(1 - \mu^2 s_2)\sin(\beta_2 - \theta_2) - \mu(1 + s_2)\cos(\beta_2 - \theta_2)}{1 + \mu^2} \right| \tag{A-178}$$

The following is found if equation A-172 is solved for F_{12}:

$$F_{12} = \frac{F_{23} A_{51} + T_2 A_{52} + I_2 N_{42} \ddot{\phi}}{A_{53}} \tag{A-179}$$

where

$$A_{51} = R_{b2} - \mu \left[s_2 a_2 - \rho_2(A_{47} + A_{50}) \right] \tag{A-180}$$

$$A_{52} = \mu\rho_2(A_{46} + A_{49}) \tag{A-181}$$

$$A_{53} = r_{b2} - \mu \left[s_1(d_1 - a_1) + \rho_2(A_{45} + A_{48}) \right] \tag{A-182}$$

DYNAMICS OF COMBINED SYSTEM IN COUPLED MOTION (APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

In order to obtain a single differential equation for the total system in coupled motion, in terms of the escape wheel variable ϕ, an appropriate expression for the contact force F_{34} must be substituted into equation A-121. To this end, equations A-149 and A-179, both expressions for the force F_{12} and originating from the expressions for the rotor and gear and pinion set no. 2, are first set equal to each other and then are solved for the force F_{23}:

$$F_{23} = \frac{1}{A_{31}A_{51}} \left[-A_{32}A_{53} - A_{31}A_{52}T_2 + A_{35}A_{53}\sin(\phi_{1C}+N_{41}\phi_T) \right.$$

$$+ A_{33}A_{53}N_{41}\dot{\phi} - A_{34}A_{53}N_{41}^2\dot{\phi}^2$$

$$\left. + (A_{53}I_{1R}N_{41} - A_{31}I_2N_{42})\ddot{\phi} \right] \qquad \text{(A-183)}$$

The just determined *expression for* F_{23} *is set equal to equation* A-166 for F_{23}, which originates from the dynamics of gear and pinion set no. 3. This results in:

$$F_{34} = \frac{1}{A_{31}A_{42}A_{51}} \left[-A_{32}A_{44}A_{53} - A_{31}A_{44}A_{52}T_2 - A_{31}A_{43}A_{51}T_3 \right.$$

$$+ A_{35}A_{44}A_{53}\sin(\phi_{1C}+N_{41}\phi_T) + A_{33}A_{44}A_{53}N_{41}\dot{\phi}$$

$$- A_{34}A_{44}A_{53}(N_{41}\dot{\phi})^2$$

$$\left. + (A_{44}A_{53}I_{1R}N_{41} - A_{31}A_{44}I_2N_{42} + A_{31}A_{51}I_3N_{43})\ddot{\phi} \right] \qquad \text{(A-184)}$$

Finally, the above is substituted into equation A-121. The following system differential equation for coupled motion is obtained:

$$A_{54}\ddot{\phi} + A_{55}\dot{\phi}^2 + A_{56}\dot{\phi} = A_{57} + A_{58}\sin(\gamma_p' - \psi - \psi_C) + A_{59}\sin(\phi_{1C} + N_{41}\phi_T) \qquad \text{(A-185)}$$

where

$$A_{54} = I_4 A_{18} + I_{PR} A_{17} U - \frac{A_{15}A_{18}A_{44}A_{53}}{A_{31}A_{42}A_{51}} N_{41} I_{1R}$$

$$+ \frac{A_{15}A_{18}A_{44}}{A_{42}A_{51}} N_{42} I_2 - \frac{A_{15}A_{18}}{A_{42}} N_{43} I_3 \qquad \text{(A-186)}$$

$$A_{55} = I_{PR} A_{17} V + A_{17} A_{21} Z^2 + \frac{A_{15}A_{18}A_{34}A_{44}A_{53}}{A_{31}A_{42}A_{51}} N_{41}^2 \qquad \text{(A-187)}$$

$$A_{56} = 2\frac{\omega^2}{|\omega|} A_{17} A_{20} Z - \frac{A_{15}A_{18}A_{33}A_{44}A_{53}}{A_{31}A_{42}A_{51}} N_{41} \qquad \text{(A-188)}$$

$$A_{57} = -A_{16}A_{18}T_4 - \frac{A_{15}A_{18}A_{43}}{A_{42}} T_3 - \frac{A_{15}A_{18}A_{44}A_{52}}{A_{42}A_{51}} T_2$$

$$- \frac{A_{15}A_{18}A_{32}A_{44}A_{53}}{A_{31}A_{42}A_{51}} - A_{17}A_{19}\omega^2 \qquad \text{(A-189)}$$

$$A_{58} = A_{17}\omega^2 m_p r_{CP} \mathcal{R}_5 \qquad \text{(A-190)}$$

$$A_{59} = \frac{A_{15}A_{18}A_{35}A_{44}A_{53}}{A_{31}A_{42}A_{51}} \qquad \text{(A-191)}$$

CONTACT FORCE EXPRESSIONS FOR COUPLED MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

The following force expressions for various contact forces are useful for strength calculations, and are applicable to both configurations.

According to equation A-184

$$F_{34} = \frac{1}{A_{31}A_{42}A_{51}} \Big[-A_{32}A_{44}A_{53} - A_{31}A_{44}A_{52}T_2 - A_{31}A_{43}A_{51}T_3$$

$$+ A_{35}A_{44}A_{53}\sin(\phi_{1C}+N_{41}\phi_T) + A_{33}A_{44}A_{53}N_{41}\dot{\phi}$$

$$- A_{34}A_{44}A_{53}(N_{41}\dot{\phi})^2 + (A_{44}A_{53}I_{1R}N_{41}$$

$$- A_{31}A_{44}I_2N_{42} + A_{31}A_{51}I_3N_{43})\ddot{\phi} \Big] \qquad \text{(A-192)}$$

According to equation A-166

$$F_{23} = \frac{F_{34}A_{42} + T_3A_{43} - I_3N_{43}\ddot{\phi}}{A_{44}} \qquad \text{(A-193)}$$

According to equation A-123

$$F_{12} = \frac{F_{23}A_{51} + T_2A_{52} + I_2N_{42}\ddot{\phi}}{A_{53}} \qquad \text{(A-194)}$$

The contact force P_n, between escape wheel and pallet, may either be expressed in terms of the escape wheel variable ϕ according to equation A-117, or in terms of the pallet variable ψ according to equation A-91. Thus,

$$P_n = \frac{-I_4\ddot{\phi} + F_{34}A_{15} - T_4A_{16}}{A_{17}} \tag{A-195}$$

or

$$P_{n\psi} = \frac{1}{A_{18}} \left[I_{PR}\ddot{\psi} + A_{21}\dot{\psi}^2 + 2\frac{\omega^2}{|\omega|} A_{20}\dot{\psi} + \omega^2 A_{19} \right.$$

$$\left. - m_p r_{CP} \mathcal{R}_5 \omega^2 \sin(\gamma_p' - \psi - \psi_C) \right] \tag{A-196}$$

DIFFERENTIAL EQUATIONS FOR FREE MOTION REGIME (APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

Both the differential equations for the free motion of the pallet and the system composed of the escape wheel, gear and pinion no. 3, gear and pinion no. 2, and the rotor may be obtained from certain coupled motion expressions.

Free Motion of Pallet

Let $P_n = 0$ in equation A-91. After some rearrangement, the following differential equation results:

$$A_{60}\ddot{\psi} + A_{21}\dot{\psi}^2 + A_{61}\dot{\psi} = - A_{62} + A_{63}\sin(\gamma_p' - \psi - \psi_C) \tag{A-197}$$

where

$$A_{60} = I_{PR}{}^{A-8} \tag{A-198}$$

A-8 For free motion, I_{PR} cannot be zero since it would make the value of $\ddot{\psi}$ in the Runge-Kutta solution indefinite (footnote A-4).

$$A_{61} = 2\,\frac{\omega^2}{|\omega|}\,A_{20} \qquad \text{(A-199)}$$

$$A_{62} = \omega^2 A_{19} \qquad \text{(A-200)}$$

$$A_{63} = \omega^2 m_p r_{CP}\,\mathcal{R}_5 \qquad \text{(A-201)}$$

Free Motion of the Escape Wheel, Gear Train, Rotor System

For the present case start by letting $P_n = 0$ in the escape wheel expression A-117, i.e.,

$$I_4\ddot{\phi} = A_{15}F_{34} - T_4A_{16} \qquad \text{(A-202)}$$

Equation A-184, which furnishes an expression for force F_{34}, is then substituted into equation A-202. This provides the desired second free motion differential equation

$$A_{64}\ddot{\phi} + A_{65}\dot{\phi}^2 - A_{66}\dot{\phi} = A_{67} + A_{68}\sin(\phi_{1C} + N_{41}\phi_T) \qquad \text{(A-203)}$$

where

$$A_{64} = I_4 - \frac{A_{15}A_{44}A_{53}}{A_{31}A_{42}A_{51}}N_{41}I_{1R} + \frac{A_{15}A_{44}}{A_{42}A_{51}}N_{42}I_2 - \frac{A_{15}}{A_{42}}N_{43}I_3 \qquad \text{(A-204)}$$

$$A_{65} = \frac{A_{15}A_{34}A_{44}A_{53}}{A_{31}A_{42}A_{51}}N_{41}^2 \qquad \text{(A-205)}$$

$$A_{66} = \frac{A_{15}A_{33}A_{44}A_{53}}{A_{31}A_{42}A_{51}}N_{41} \qquad \text{(A-206)}$$

$$A_{67} = -A_{16}T_4 - \frac{A_{15}A_{43}}{A_{42}} T_3 - \frac{A_{15}A_{44}A_{52}}{A_{42}A_{51}} T_2 - \frac{A_{15}A_{32}A_{44}A_{53}}{A_{31}A_{42}A_{51}} \qquad \text{(A-207)}$$

$$A_{68} = \frac{A_{15}A_{35}A_{44}A_{53}}{A_{31}A_{42}A_{51}} \qquad \text{(A-208)}$$

CONTACT FORCE EXPRESSIONS FOR FREE MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

The contact force F_{F34} may be obtained from equation A-117 by setting P_n equal to zero, so that

$$F_{F34} = \frac{I_4\ddot{\phi} + T_4A_{16}}{A_{15}} \qquad \text{(A-209)}$$

The expression for the contact force F_{F23} has the same form as equation A-193 since it originates from the dynamics of gear and pinion set no. 3

$$F_{F23} = \frac{F_{F34}A_{42} + T_3A_{43} - I_3N_{43}\ddot{\phi}}{A_{44}} \qquad \text{(A-210)}$$

Similarly, the form of F_{F12} is like that of equation A-194

$$F_{F12} = \frac{F_{F23}A_{51} + T_2A_{52} + I_2N_{42}\ddot{\phi}}{A_{53}} \qquad \text{(A-211)}$$

CHANGES IN IMPACT EXPRESSIONS
(APPLICABLE TO BOTH CONFIGURATIONS WITH PROPER s_6)

While generally the impact description of reference A-1 remains unchanged, the total moment of inertia I_{STOT} of the escape wheel is now increased, since it must also account for the presence of the gear train and the rotor. Therefore,

$$I_{STOT} = I_4 + I_3 N_{43}^2 + I_2 N_{42}^2 + I_1 N_{41}^2 \tag{A-212}$$

where

I_4 = escape wheel - pinion no. 4 moment of inertia

I_3 = gear and pinion set no. 3 moment of inertia

I_2 = gear and pinion set no. 2 moment of inertia

I_1 = rotor moment of inertia

See equations A-125, A-158, and A-171 for the transmission ratios.

REFERENCES

A-1. G. G. Lowen and F. R. Tepper, "Dynamics of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.

A-2. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX B

DYNAMICS OF ROTOR DRIVEN S&A DEVICE WITH A TWO-PASS INVOLUTE GEAR TRAIN AND A PIN PALLET RUNAWAY ESCAPEMENT

DESCRIPTION OF SYSTEMS AND OUTLINE OF DERIVATIONS

Figures B-1 and B-2 show the two configurations of the S&A mechanism discussed in this appendix. These devices differ from those described in appendix A because they contain only two step-up gear meshes. Since the escape wheel still is assumed to have counterclockwise rotation, the motion of the rotor must also be counterclockwise, and the gear and pinion set no. 2 must turn in a clockwise direction. This requires certain changes in the rotor geometry as well as in the direction of the lines of action of the gear contact forces F_{12} and F_{23}. Naturally, all quantities previously associated with gear and pinion set no. 3 are now absent.

The general approach to the modeling of these devices is the same as that used in appendix A. While the derivations are specifically for configuration no. 1, the results are applicable to both configurations as long as the appropriate fuze body angles are used.

GEOMETRY OF FUZE BODY CONFIGURATIONS

Fuze Body Configuration No. 1

Figure B-3 indicates the following relationships for the angles γ_i, δ_i and β_i for configuration no. 1:

According to equation A-1 (app A)

$$\gamma_2 = \cos^{-1}\left[\frac{\mathcal{R}_1^2 + \mathcal{R}_2^2 - (R_{p1} + r_{p2})^2}{2\,\mathcal{R}_1\,\mathcal{R}_2}\right] \tag{B-1}$$

Further, according to equation A-2 (app A)

$$\gamma_3' = \cos^{-1}\left[\frac{\mathcal{R}_2^2 + \mathcal{R}_3^2 - (R_{p2} + r_{p3})^2}{2\,\mathcal{R}_2\,\mathcal{R}_3}\right] \tag{B-2}$$

Finally, from equation A-3 (app A)

$$\gamma_3 = \gamma_2 + \gamma_3' \tag{B-3}$$

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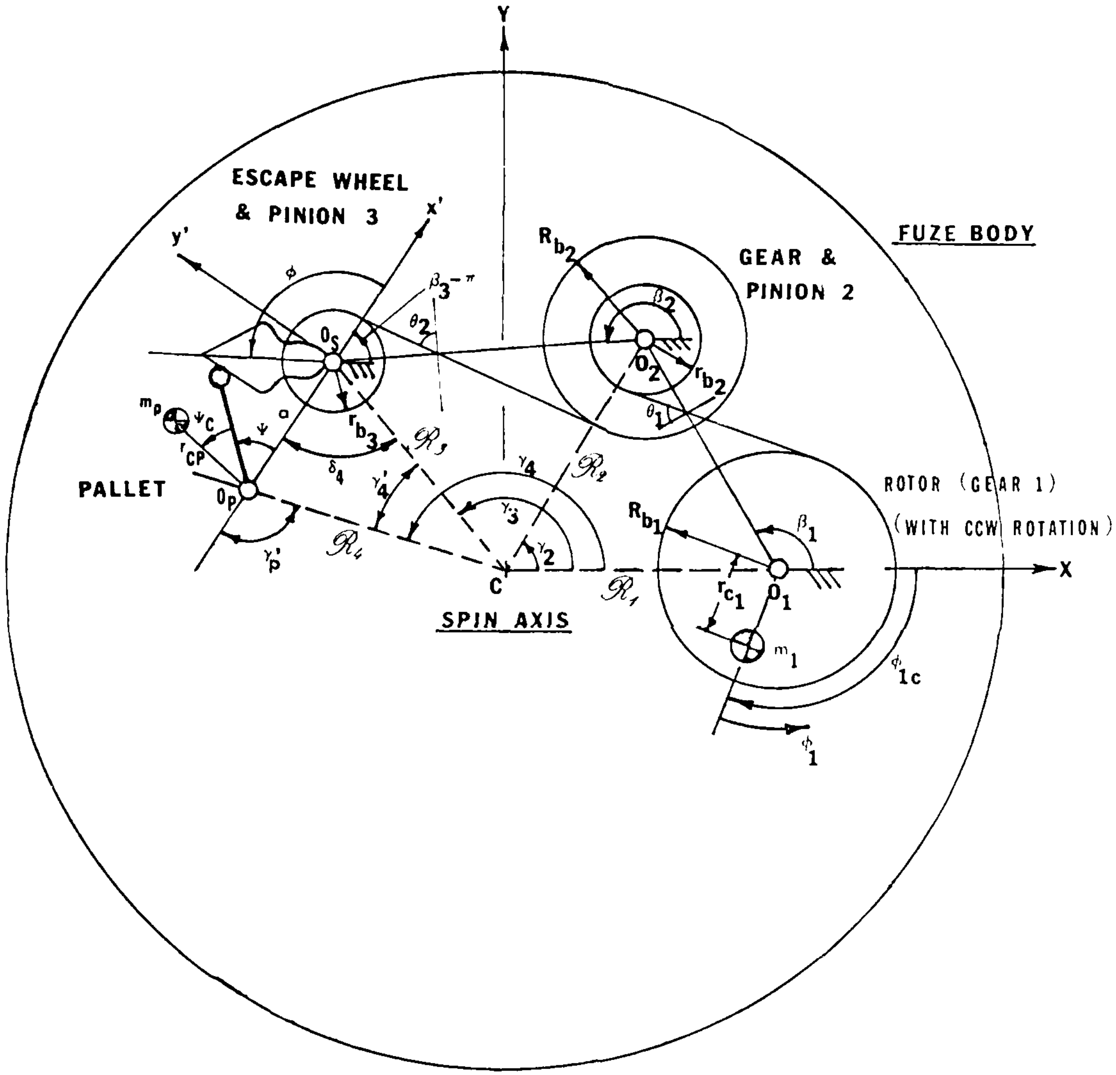

Figure B-1. Rotor driven S&A device with two pass step-up gear train - configuration no. 1

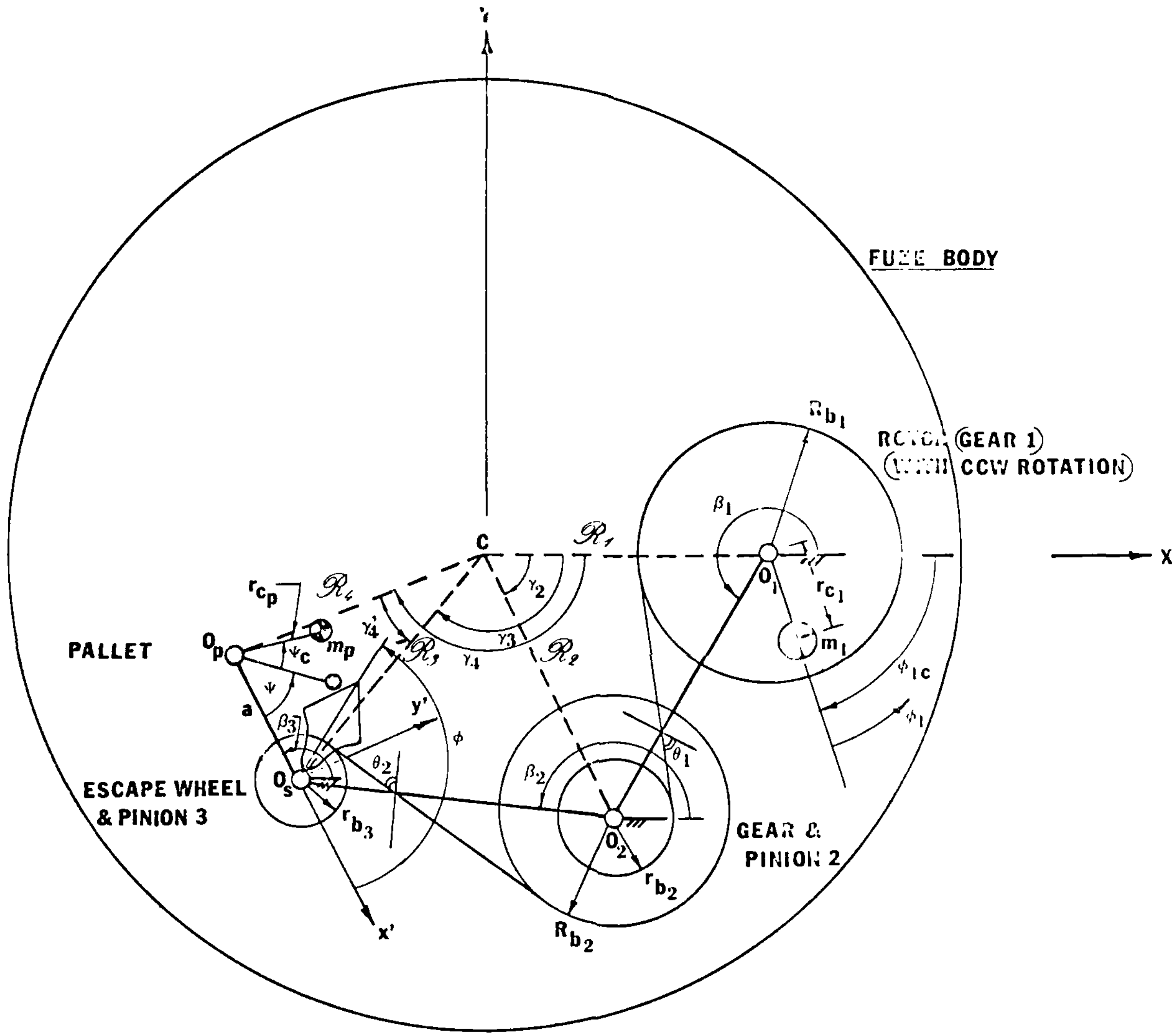

Figure B-2. Rotor driven S&A device with two pass step-up gear train configuration no. 2

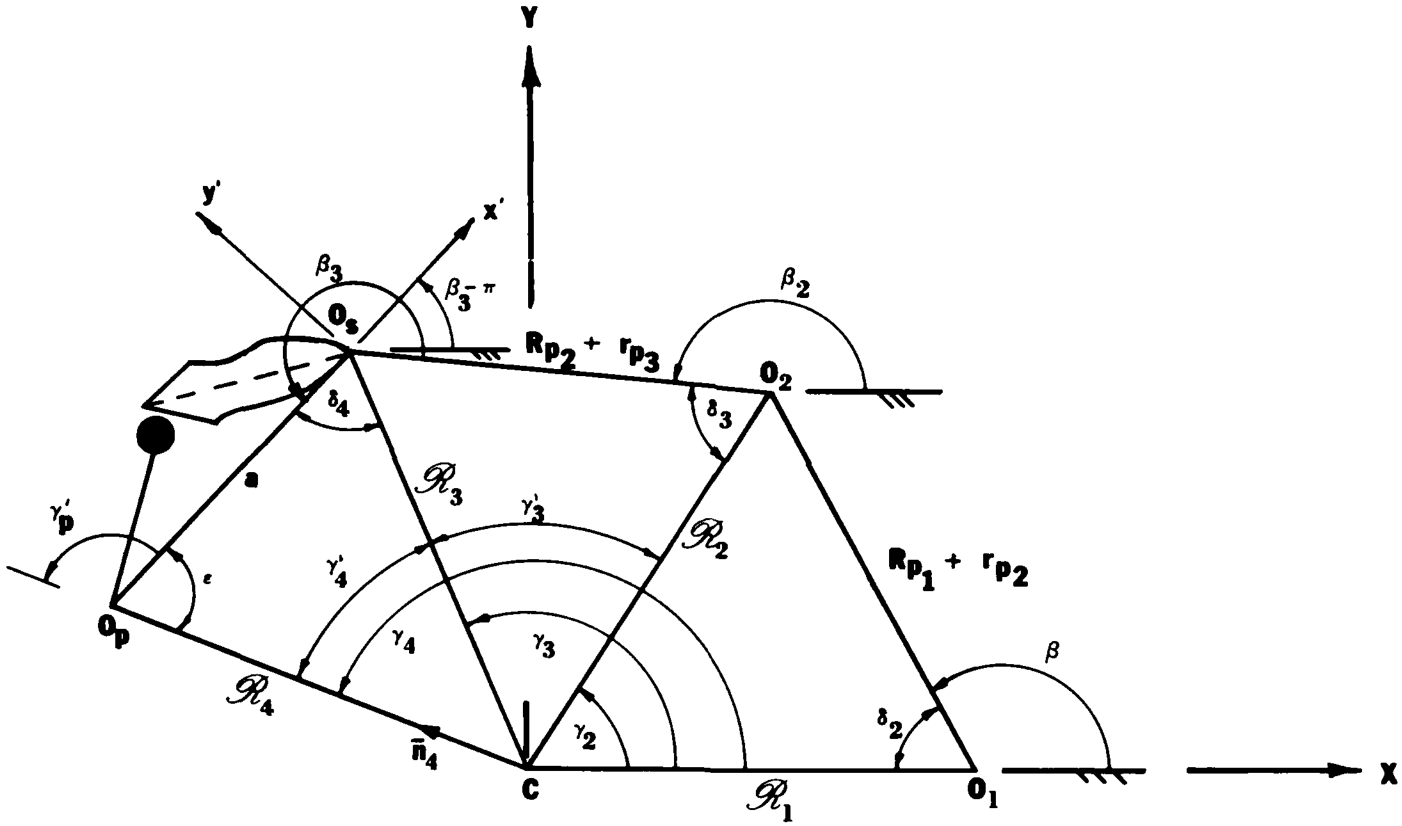

Figure B-3. Fuze body configuration no. 1 (two pass)

The angle γ_4' must be newly derived. Thus,

$$\gamma_4' = \cos^{-1}\left[\frac{\mathcal{R}_3^2 + \mathcal{R}_4^2 - a^2}{2\,\mathcal{R}_3\,\mathcal{R}_4}\right] \tag{B-4}$$

Then, as in equation A-5 (app A)

$$\gamma_4 = \gamma_3 + \gamma_4' \tag{B-5}$$

Angles δ_i

The angles δ_2 and δ_3 can be taken directly from equations A-9 and A-10 (app A), respectively, i.e.,

$$\delta_2 = \cos^{-1}\left[\frac{(R_{p1} + r_{p2})^2 + \mathcal{R}_1^2 - \mathcal{R}_2^2}{2\,\mathcal{R}_1(R_{p1} + r_{p2})}\right] \tag{B-6}$$

and

$$\delta_3 = \cos^{-1}\left[\frac{(R_{p2} + r_{p3})^2 + \mathcal{R}_2^2 - \mathcal{R}_3^2}{2\,\mathcal{R}_2\,(R_{p2} + r_{p3})}\right] \tag{B-7}$$

The angle δ_4 must take the pivot-to-pivot distance a of the escapement into account. Therefore,

$$\delta_4 = \cos^{-1}\left[\frac{a^2 + \mathcal{R}_3^2 - \mathcal{R}_4^2}{2a\,\mathcal{R}_3}\right] \tag{B-8}$$

Angles β_i

The angles β_1 and β_2 may also be taken directly from equations A-14 and A-15 (app A), respectively, i.e.,

$$\beta_1 = \pi - \delta_2 \tag{B-9}$$

and

$$\beta_2 = \gamma_2 + \pi - \delta_3 \tag{B-10}$$

The angle β_3 is found with the help of angle δ_4 of equation B-8. Then, similar to equation A-16 (app A)

$$\beta_3 = \gamma_3 + \pi - \delta_4 \tag{B-11}$$

Figure B-3 shows the angle γ_p' between the positive X- axis and the unit vector $\bar{n}_4$. It is given by

$$\gamma_p' = \pi - \varepsilon \tag{B-12}$$

where ε is obtained with the help of equations B-4 and B-8

$$\varepsilon = \pi - \delta_4 - \gamma_4', \tag{B-13}$$

and therefore

$$\gamma_p' = \delta_4 + \gamma_4' \tag{B-14}$$

The unit vector $\bar{n}_4$ is expressed in terms of the primed coordinate system as follows:

$$\bar{n}_4 = \cos\gamma_p' \bar{i}' + \sin\gamma_p' \bar{j}' \tag{B-15}$$

Further, the unit vectors $\bar{i}'$ and $\bar{j}'$, when expressed in the x-y system, become

$$\bar{i}' = \cos(\beta_3 - \pi)\bar{i} + \sin(\beta_3 - \pi)\bar{j}$$

or

$$\bar{i}' = -\cos\beta_3\bar{i} - \sin\beta_3\bar{j} \tag{B-16}$$

and

$$\bar{j}' = \bar{k}' \times \bar{i}' = \sin\beta_3\bar{i} - \cos\beta_3\bar{j} \tag{B-17}$$

Fuze Body Configuration No. 2

Figure B-4 is used to define the angles γ_i, δ_i, and β_i of configuration no. 2.

Angles γ_i

Since these angles are defined in the clockwise direction with respect to the body fixed X- axis, their value must be negative, as is the case for the three pass configuration no. 2 of appendix A.

According to equation A-24 (app A)

$$\gamma_2 = -\cos^{-1}\left[\frac{\mathcal{R}_1^2 + \mathcal{R}_2^2 - (R_{p1} + r_{p2})^2}{2\,\mathcal{R}_1\,\mathcal{R}_2}\right] \tag{B-18}$$

Angle γ_3' is given by equation B-2, and with that γ_3 becomes

$$\gamma_3 = \gamma_2 - \gamma_3' \tag{B-19}$$

The negative sign for γ_3' is necessary in order to make γ_3 negative.

The angle γ_4 is given by equation B-4. It allows the following expression for angle γ_4

$$\gamma_4 = \gamma_3 - \gamma_4' \tag{B-20}$$

Again, γ_4' must have a negative sign to make γ_4 negative.

Angles δ_i

The angles δ_2, δ_3, and δ_4 can be taken directly from equations B-6, B-7, and B-8, respectively.

Angles β_i

As in equation A-28 (app A)

$$\beta_1 = \pi + \delta_2 \tag{B-21}$$

Further, according to equation A-29 (app A)

$$\beta_2 = \gamma_2 + \pi + \delta_3 \tag{B-22}$$

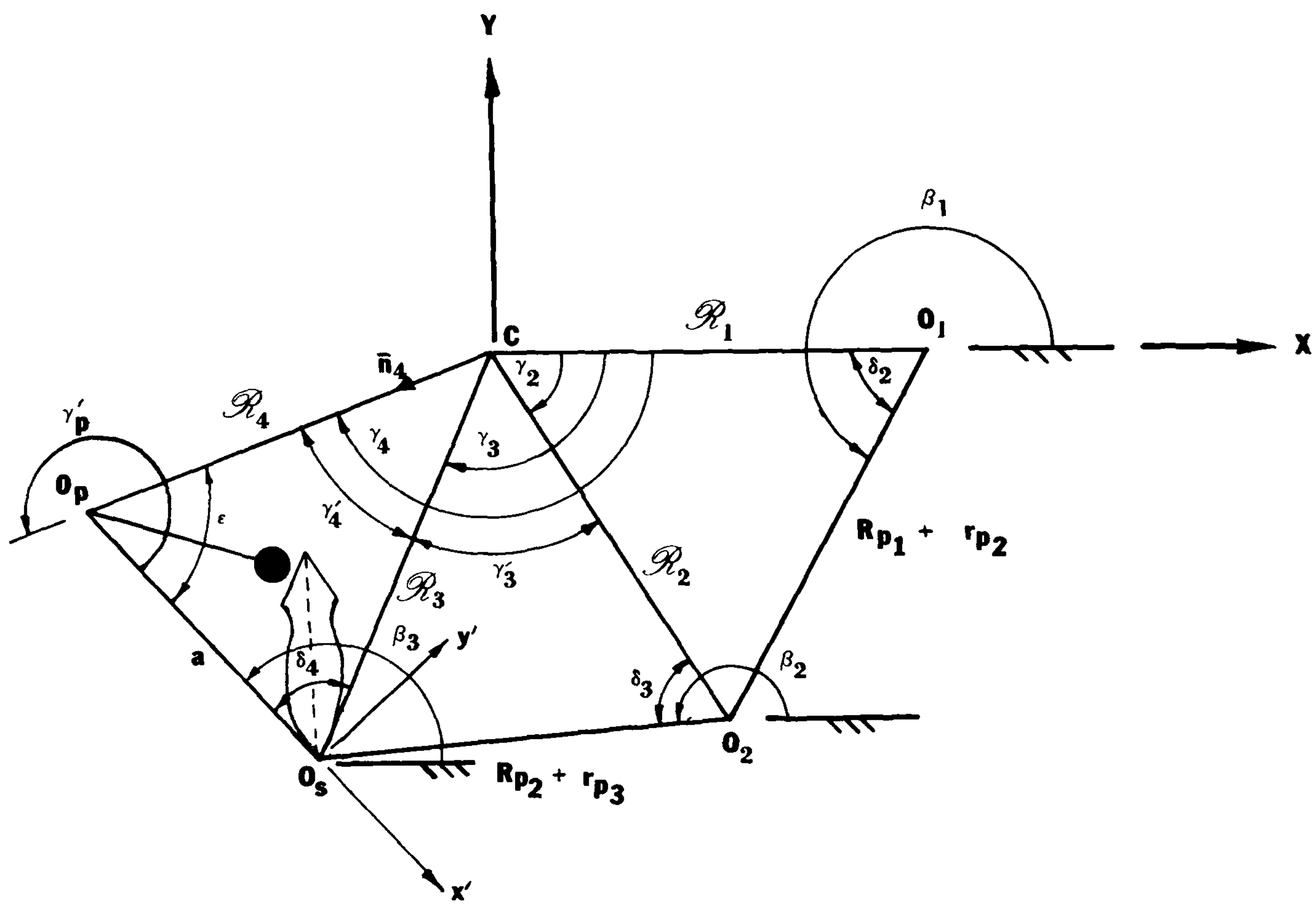

Figure B-4. Fuze body configuration no. 2 (two pass)

Finally, according to equation A-30 (app A)

$$\beta_3 = \gamma_3 + \pi + \delta_4 \tag{B-23}$$

Figure B-4 shows the angle γ_p' between the positive x'- axis and the unit vector $\bar{n}_4$. This angle is given by

$$\gamma_p' = \pi + \varepsilon \tag{B-24}$$

where

$$\varepsilon = \pi - \delta_4 - \gamma_4' \tag{B-25}$$

Therefore,

$$\gamma_p' = 2\pi - \delta_4 - \gamma_4' \tag{B-26}$$

The unit vector $\bar{n}_4$ can again be expressed in terms of the primed coordinate system as

$$\bar{n}_4 = \cos\gamma_p'\bar{i}' + \sin\gamma_p'\bar{j}' \tag{B-27}$$

In a manner parallel to that used for equations A-36 and A-37 (app A), the units vectors $\bar{i}'$ and $\bar{j}'$ in the X-Y system are expressed as follows:

$$\bar{i}' = -\cos\beta_3\bar{i} - \sin\beta_3\bar{j} \tag{B-28}$$

and

$$\bar{j}' = \sin\beta_3\bar{i} - \cos\beta_3\bar{j} \tag{B-29}$$

Common Computational Expressions for Both Configurations

In order to find common programming expressions for all angles of both configurations, with the exception of the angles γ_p' of equations B-14 and B-26, the following signum function s_6 is again introduced

$$s_6 = +1 \text{ for configuration no. 1} \tag{B-30}$$

$$s_6 = -1 \text{ for configuration no. 2} \tag{B-31}$$

This leads to the following expressions:

according to equations B-1 and B-18

$$\gamma_2 = s_6 \cos^{-1}\left[\frac{\mathcal{R}_1^2 + \mathcal{R}_2^2 - (R_{p1} + r_{p2})^2}{2\,\mathcal{R}_1\,\mathcal{R}_2}\right] \tag{B-32}$$

according to equation B-2

$$\gamma_3' = \cos^{-1}\left[\frac{\mathcal{R}_2^2 + \mathcal{R}_3^2 - (R_{p2} + r_{p3})^2}{2\,\mathcal{R}_2\,\mathcal{R}_3}\right] \tag{B-33}$$

according to equations B-3 and B-19

$$\gamma_3 = \gamma_2 + s_6\gamma_3' \tag{B-34}$$

according to equation B-4

$$\gamma_4' = \cos^{-1}\left[\frac{\mathcal{R}_3^2 + \mathcal{R}_4^2 - a^2}{2\,\mathcal{R}_3\,\mathcal{R}_4}\right] \tag{B-35}$$

according to equations B-5 and B-20

$$\gamma_4 = \gamma_3 + s_6\gamma_4' \tag{B-36}$$

according to equations B-6 through B-8, respectively

$$\delta_2 = \cos^{-1}\left[\frac{(R_{p1} + r_{p2})^2 + \mathcal{R}_1^2 - \mathcal{R}_2^2}{2\,\mathcal{R}_1(R_{p1} + r_{p2})}\right] \tag{B-37}$$

$$\delta_3 = \cos^{-1}\left[\frac{(R_{p2} + r_{p3})^2 + \mathcal{R}_2^2 - \mathcal{R}_3^2}{2\,\mathcal{R}_2\,(R_{p2} + r_{p3})}\right] \tag{B-38}$$

$$\delta_4 = \cos^{-1}\left[\frac{a^2 + \mathcal{R}_3^2 - \mathcal{R}_4^2}{2a\,\mathcal{R}_3}\right] \tag{B-39}$$

according to equations B-9 and B-21

$$\beta_1 = \pi - s_6\delta_2 \tag{B-40}$$

according to equations B-10 and B-22

$$\beta_2 = \gamma_2 + \pi - s_6\delta_3 \tag{B-41}$$

according to equations B-11 and B-23

$$\beta_3 = \gamma_2 + \pi - s_6\delta_4 \tag{B-42}$$

The signum function s_6 will also be useful in conditional statements which distinguish between the γ_p''s of configuration no. 1 and 2, as given by equations B-14 and B-26, respectively.

The expressions for the unit vectors $\bar{i}'$ and $\bar{j}'$ are identical for both configurations according to equations B-16 and B-17 as well as equations B-28 and B-29. Thus,

$$\bar{i}' = -\cos\beta_3\bar{i} - \sin\beta_3\bar{j} \tag{B-43}$$

and

$$\bar{j}' = \sin\beta_3\bar{i} - \cos\beta_3\bar{j} \tag{B-44}$$

DYNAMICS OF PALLET IN COUPLED MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

Equation A-95, appendix A, which gives the contact force P_n between pallet and escape wheel, may be readily adapted to the present two pass mechanism. It is only required that, depending on configuration, the angle γ' is computed according to either equation B-14 or equation B-26. Further, the distance from the spin axis to the pallet pivot is now given by $\mathcal{R}_4$ rather than by $\mathcal{R}_5$. Thus equation A-95 becomes

$$P_n = \frac{1}{A_{18}}\Big[I_{PR}U\ddot{\phi} + (A_{21}Z^2 + I_{PR}V)\dot{\phi}^2 + 2\frac{\omega^2}{|\omega|}A_{20}Z\dot{\phi} + \omega^2 A_{19}$$

$$- m_p r_{CP}\,\mathcal{R}_4\omega^2\sin(\gamma_P' - \psi - \psi_C)\Big] \qquad \text{(B-45)}$$

The parameters A_1 to A_8, A_{18} to A_{21} and I_{PR} may essentially be taken directly from equations A-70 through A-77 and equations A-84 through A-90, appendix A. In equations A-71 and A-75 it is necessary to substitute $\mathcal{R}_4$ for $\mathcal{R}_5$.

DYNAMICS OF ESCAPE WHEEL IN COUPLED MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH THE APPROPRIATE s_6)

The analysis of the escape wheel can be taken over from appendix A, once the appropriate signum function s_6 has been chosen for the given configuration and the following changes in nomenclature have been made:

β_4	becomes	β_3
θ_3	becomes	θ_2
m_4	becomes	m_3
$\mathcal{R}_4$	becomes	$\mathcal{R}_3$
I_4	becomes	I_3
γ_4	becomes	γ_3
s_3	becomes	s_2

d_3	becomes	d_2
a_3	becomes	a_2
$\bar{n}_{34}$	becomes	$\bar{n}_{23}$
$\bar{n}_{N34}$	becomes	$\bar{n}_{N23}$
F_{34}	becomes	F_{23}
F_{x4}	becomes	F_{x3}
ρ_4	becomes	ρ_3
F_{y4}	becomes	F_{y3}
r_{b4}	becomes	r_{b3}
T_4	becomes	T_3

Note that the meanings of s_4 and s_5 remain unchanged (eq A-59 and A-60).

Similar to equation A-117, the contact force equation, as derived for the escape wheel, then has the following form:

$$P_n = \frac{-I_3\ddot{\phi} + F_{23}A_{15} - T_3A_{16}}{A_{17}} \qquad \text{(B-46)}$$

where now

$$A_{15} = r_{b3} - \mu\left[s_2(d_2 - a_2) + \rho_3(A_{10} + A_{13})\right] \qquad \text{(B-47)}$$

$$A_{16} = \mu\rho_3(A_{11} + A_{14}) \qquad \text{(B-48)}$$

$$A_{17} = A_1' + \mu_1 s_4 B_1' + \mu\rho_3(A_9 + A_{12}) \tag{B-49}$$

and similarly

$$A_9 = \left| \frac{-(\mu_1 s_4 - \mu)\sin(\phi-\alpha+\beta_3) + (1+\mu\mu_1 s_4)\cos(\phi-\alpha+\beta_3)}{1 + \mu^2} \right| \tag{B-50}$$

$$A_{10} = \left| \frac{-\mu(1-s_2)\sin(\beta_2+\theta_2) - (1+\mu^2 s_2)\cos(\beta_2+\theta_2)}{1 + \mu^2} \right| \tag{B-51}$$

$$A_{11} = \left| \frac{\sin\gamma_3 - \mu\cos\gamma_3}{1 + \mu^2} \right| \tag{B-52}$$

$$A_{12} = \left| \frac{(1+\mu_1\mu s_4)\sin(\phi-\alpha+\beta_3) + (s_4\mu_1-\mu)\cos(\phi-\alpha+\beta_3)}{1 + \mu^2} \right| \tag{B-53}$$

$$A_{13} = \left| \frac{-(1+\mu^2 s_2)\sin(\beta_2+\theta_2) + \mu(1-s_2)\cos(\beta_2+\theta_2)}{1 + \mu^2} \right| \tag{B-54}$$

$$A_{14} = \left| \frac{-\cos\gamma_3 - \mu\sin\gamma_3}{1 + \mu^2} \right| \tag{B-55}$$

COMBINED COUPLED MOTION DIFFERENTIAL EQUATION FOR ESCAPE WHEEL AND PALLET (APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

Equations B-45 and B-46, are now set equal to each other in order to obtain a combined differential equation for the escapement. This leads to

$$\left[I_3 A_{18} + I_{PR} A_{17} U \right] \ddot{\phi} + \left[I_{PR} A_{17} V + A_{17} A_{21} Z^2 \right] \dot{\phi}^2$$

$$+ 2 \frac{\omega^2}{|\omega|} A_{17} A_{20} Z \dot{\phi}$$

$$= A_{15} A_{18} F_{23} - A_{16} A_{18} T_3 - A_{17} \omega^2 \left[A_{19} - m_p r_{CP} \mathcal{R}_4 \sin(\gamma_P' - \psi - \psi_C) \right] \qquad \text{(B-56)}$$

Again, it is necessary now to determine an expression for the contact force F_{23}.

DYNAMICS OF ROTOR (Gear No. 1) (APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

Figure B-5 shows a free body diagram of the rotor of configuration no. 1, which moves in a counterclockwise direction. The acceleration of its center of mass is given by equation A-122, appendix A.

Since the motion of the rotor must be expressed again in terms of the escape wheel variables, use must be made of

$$\dot{\phi}_1 = N_{31} \dot{\phi} \qquad \text{(B-57)}$$

and

$$\ddot{\phi}_1 = N_{31} \ddot{\phi} \qquad \text{(B-58)}$$

where

$$N_{31} = \frac{N_{P3}}{N_{G2}} \times \frac{N_{P2}}{N_{G1}} \qquad \text{(B-59)}$$

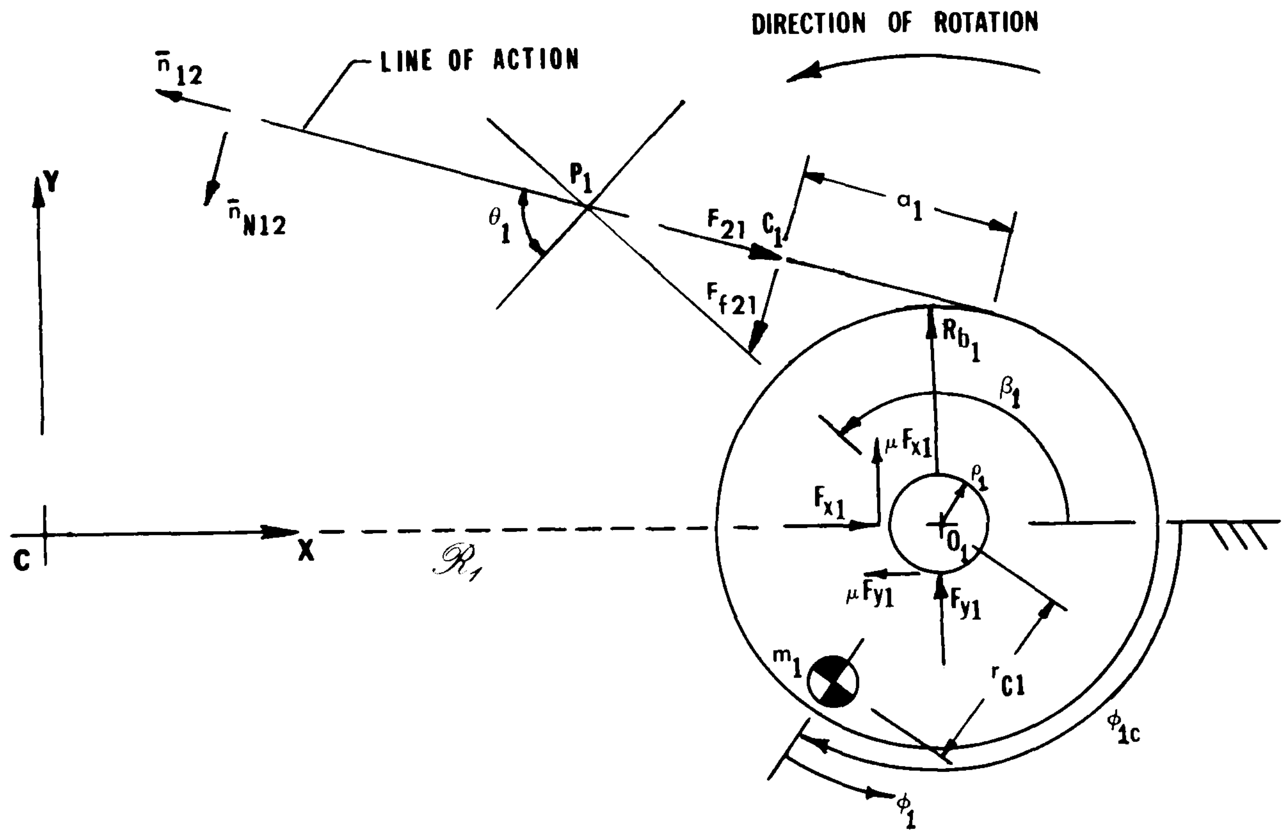

Figure B-5. Free body diagram of rotor

The rotor angle $\phi_{1C} + \phi_1$ is expressed in terms of the total escape wheel rotation ϕ_T

$$\phi_{1C} + \phi_1 = \phi_{1C} + N_{31}\ \phi_T \qquad \text{(B-60)}$$

(For details, see program description.)

Newton's force equation may now be written in the form of equation A-128. The tooth forces

$$\bar{F}_{21} = -F_{12}\bar{n}_{12} \qquad \text{(B-61)}$$

and

$$\bar{F}_{f21} = \mu s_1 F_{12}\bar{n}_{N12} \qquad \text{(B-62)}$$

have the appropriate directions to account for friction.

Thus

$$-F_{12}\bar{n}_{12} + \mu s_1 F_{12}\bar{n}_{N12} + F_{x1}\bar{i} - \mu F_{y1}\bar{i} + F_{y1}\bar{j} + \mu F_{x1}\bar{j}$$

$$= m_1 \left\{ -\omega^2 R_1\bar{i} - (\omega + N_{31}\dot{\phi})^2 r_{C1}\ \left[\cos(\phi_{1C}+N_{31}\phi_T)\bar{i} + \sin(\phi_{1C}+N_{31}\phi_T)\bar{j}\right]\right.$$

$$\left. + N_{31}\ddot{\phi} r_{C1}\ \left[-\sin(\phi_{1C}+N_{31}\phi_T)\bar{i} + \cos(\phi_{1C}+N_{31}\phi_T)\bar{j}\right]\right\} \qquad \text{(B-63)}$$

where

$$\bar{n}_{12} = -\sin(\beta_1 - \theta_1)\bar{i} + \cos(\beta_1 - \theta_1)\bar{j} \qquad \text{(B-64)}$$

$$\bar{n}_{N12} = -\cos(\beta_1 - \theta_1)\bar{i} - \sin(\beta_1 - \theta_1)\bar{j} \qquad \text{(B-65)}$$

The moment equation must be written in the manner of equation A-61 with respect to the accelerated point 0_1. The pivot reactions $\tilde{F}_{x1}$ and $\tilde{F}_{y1}$ are written such that the associated friction moments retard the counterclockwise rotation of the rotor. This leads to

$$-F_{12}R_{b1} + \mu s_1 a_1 F_{12} - \mu\rho_1(\tilde{F}_{x1} + \tilde{F}_{y1})$$

$$= m_1\omega^2 \mathcal{R}_1 r_{C1}\sin(\phi_{1C}+N_{31}\phi_T) + I_1 N_{31}\ddot{\phi} \tag{B-66}$$

The forces $\tilde{F}_{x1}$ and $\tilde{F}_{y1}$ are obtained after the simultaneous solution of the following component expressions of equation B-63 for F_{x1} and F_{y1}:

$$F_{12}\sin(\beta_1-\theta_1) + \mu s_1 F_{12}\cos(\beta_1-\theta_1) + F_{x1} - \mu F_{y1}$$

$$= m_1\left[-\omega^2 \mathcal{R}_1 - (\omega+N_{31}\dot{\phi})^2 r_{C1}\cos(\phi_{1C}+N_{31}\phi_T) - N_{31}\ddot{\phi} r_{C1}\sin(\phi_{1C}+N_{31}\phi_T)\right] \tag{B-67}$$

and

$$-F_{12}\cos(\beta_1-\theta_1) - \mu s_1 F_{12}\sin(\beta_1-\theta_1) + F_{y1} + \mu F_{x1}$$

$$= m_1\left[-(\omega+N_{31}\dot{\phi})^2 r_{C1}\sin(\phi_{1C}+N_{31}\phi_T) + N_{31}\ddot{\phi} r_{C1}\cos(\phi_{1C}+N_{31}\phi_T)\right] \tag{B-68}$$

Simultaneous solution of the above furnishes

$$\tilde{F}_{x1} = F_{12}A_{23} \pm \omega^2 A_{24} \pm 2\frac{\omega^2}{|\omega|} N_{31}\dot{\phi}A_{25} \pm (N_{31}\dot{\phi})^2 A_{25} \pm N_{31}\ddot{\phi}A_{26} \tag{B-69}$$

$$\tilde{F}_{y1} = F_{12}A_{27} \pm \omega^2 A_{28} \pm 2\frac{\omega^2}{|\omega|} N_{31}\dot{\phi}A_{29} \pm (N_{31}\dot{\phi})^2 A_{29} \pm N_{31}\ddot{\phi}A_{30} \tag{B-70}$$

where

$$A_{23} = \left| \frac{(1-\mu^2 s_1)\sin(\beta_1-\theta_1) - \mu(1+s_1)\cos(\beta_1-\theta_1)}{1+\mu^2} \right| \tag{B-71}$$

$$A_{24} = \left| \frac{m_1 \left[\mathcal{R}_1 + r_{C1}(\cos(\phi_{1C}+N_{31}\phi_T) + \mu\sin(\phi_{1C}+N_{31}\phi_T))\right]}{1+\mu^2} \right| \tag{B-72}$$

$$A_{25} = \left| \frac{m_1 r_{C1} \left[\cos(\phi_{1C}+N_{31}\phi_T) + \mu\sin(\phi_{1C}+N_{31}\phi_T)\right]}{1+\mu^2} \right| \tag{B-73}$$

$$A_{26} = \left| \frac{m_1 r_{C1} \left[\sin(\phi_{1C}+N_{31}\phi_T) - \mu\cos(\phi_{1C}+N_{31}\phi_T)\right]}{1+\mu^2} \right| \tag{B-74}$$

$$A_{27} = \left| \frac{\mu(1+s_1)\sin(\beta_1-\theta_1) + (1-\mu^2 s_1)\cos(\beta_1-\theta_1)}{1+\mu^2} \right| \tag{B-75}$$

$$A_{28} = \left| \frac{\mu m_1 \mathcal{R}_1 + m_1 r_{C1} \left[\mu\cos(\phi_{1C}+N_{31}\phi_T) - \sin(\phi_{1C}+N_{31}\phi_T)\right]}{1+\mu^2} \right| \tag{B-76}$$

$$A_{29} = \left| \frac{m_1 r_{C1} \left[\mu\cos(\phi_{1C}+N_{31}\phi_T) - \sin(\phi_{1C}+N_{31}\phi_T)\right]}{1+\mu^2} \right| \tag{B-77}$$

$$A_{30} = \left| \frac{m_1 r_{C1} \left[\mu\sin(\phi_{1C}+N_{31}\phi_T) + \cos(\phi_{1C}+N_{31}\phi_T)\right]}{1+\mu^2} \right| \tag{B-78}$$

Equations B-69 and B-70 are now substituted into the moment equation B-66

$$-F_{12}R_{b1} + \mu s_1 a_1 F_{12} - \mu\rho_1 \Big[F_{12}(A_{23}+A_{27}) \pm \omega^2 (A_{24}+A_{28})$$

$$\pm 2\frac{\omega^2}{|\omega|} N_{31}\dot{\phi}(A_{25}+A_{29}) \pm (N_{31}\dot{\phi})^2 (A_{25}+A_{29}) \pm N_{31}\ddot{\phi}(A_{26}+A_{30})\Big]$$

$$= m_1\omega^2 \mathcal{R}_1 r_{C1}\sin(\phi_{1C}+N_{31}\phi_T) + I_1 N_{31}\ddot{\phi} \qquad \text{(B-79)}$$

In order to have the pivot friction moment negative, the following terms on the left hand side of equation B-79 must be negative:

$$\mu\rho_1 F_{12}\,(A_{23} + A_{27})$$

$$\mu\rho_1\omega^2\,(A_{24} + A_{28})$$

$$\mu\rho_1\,(N_{31}\dot{\phi})^2\,(A_{25} + A_{29})$$

$$2|\mu|\rho_1 \frac{\omega^2}{|\omega|} N_{31}\,\dot{\phi}\,(A_{25} + A_{29})$$

(With $N_{31}\dot{\phi}$ positive, μ must be absolute. See discussion following equation A-147).) The term $\mu\rho_1 N_{31}\ddot{\phi}\,(A_{26} + A_{30})$ is treated in the same manner as was shown in connection with equation A-149, appendix A. (See the discussion in appendix F.)

The above considerations give the moment equation the following form:

$$-F_{12}\left[R_{b1} - \mu s_1 a_1 + \mu\rho_1(A_{23}+A_{27})\right] - \omega^2 \mu\rho_1(A_{24}+A_{28})$$

$$-\frac{2\mu\rho_1\omega^2 N_{31}\dot{\phi}}{|\omega|}(A_{25}+A_{29}) - \mu\rho_1 (N_{31}\dot{\phi})^2 (A_{25} + A_{29})$$

$$= m_1\omega^2 \mathcal{R}_1 r_{C1}\sin(\phi_{1C}+N_{31}\phi_T) + (I_1 \pm \mu\rho_1(A_{26}+A_{30}))N_{31}\ddot{\phi} \qquad \text{(B-80)}$$

Finally, the above expression is solved for F_{12}, i.e.,

$$F_{12} = \frac{-A_{32} - A_{33}N_{31}\dot{\phi} - A_{34}(N_{31}\dot{\phi})^2 - A_{35}\sin(\phi_{1C}+N_{31}\phi_T) - I_{1R}N_{31}\ddot{\phi}}{A_{31}} \qquad \text{(B-81)}$$

where

$$A_{31} = R_{b1} - \mu s_1 a_1 + \mu\rho_1(A_{23} + A_{27}) \qquad \text{(B-82)}$$

$$A_{32} = \mu\rho_1\omega^2(A_{24} + A_{28}) \qquad \text{(B-83)}$$

$$A_{33} = 2|\mu|\rho_1 \frac{\omega^2}{|\omega|}(A_{25} + A_{29}) \qquad \text{(B-84)}$$

$$A_{34} = \mu\rho_1(A_{25} + A_{29}) \qquad \text{(B-85)}$$

$$A_{35} = m_1 \mathcal{R}_1 r_{C1}\omega^2 \qquad \text{(B-86)}$$

$$I_{1R} = I_1 + |\mu|\rho_1(A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have the same signs} \tag{B-87}$$

$$I_{1R} = I_1 - |\mu|\rho_1(A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have opposite signs} \tag{B-88}$$

DYNAMICS OF GEAR AND PINION SET NO. 2
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

The free body diagram of gear and pinion set no. 2 of configuration no. 1 is shown in figure B-6. Its force equation is written as follows with the D'Alembert force

$$T_2 = m_2 \mathcal{R}_2 \omega^2 \tag{B-89}$$

Thus

$$-F_{23}\bar{n}_{23} - s_2\mu F_{23}\bar{n}_{N23} + F_{12}\bar{n}_{12} - \mu s_1 F_{12}\bar{n}_{N12} + F_{x2}\bar{i} + \mu F_{y2}\bar{i}$$

$$+ F_{y2}\bar{j} - \mu F_{x2}\bar{j} + T_2(\cos\gamma_2\bar{i} + \sin\gamma_2\bar{j}) = 0 \tag{B-90}$$

where

$$\bar{n}_{23} = \sin(\beta_2 + \theta_2)\bar{i} - \cos(\beta_2 + \theta_2)\bar{j} \tag{B-91}$$

$$\bar{n}_{N23} = \cos(\beta_2 + \theta_2)\bar{i} + \sin(\beta_2 + \theta_2)\bar{j} \tag{B-92}$$

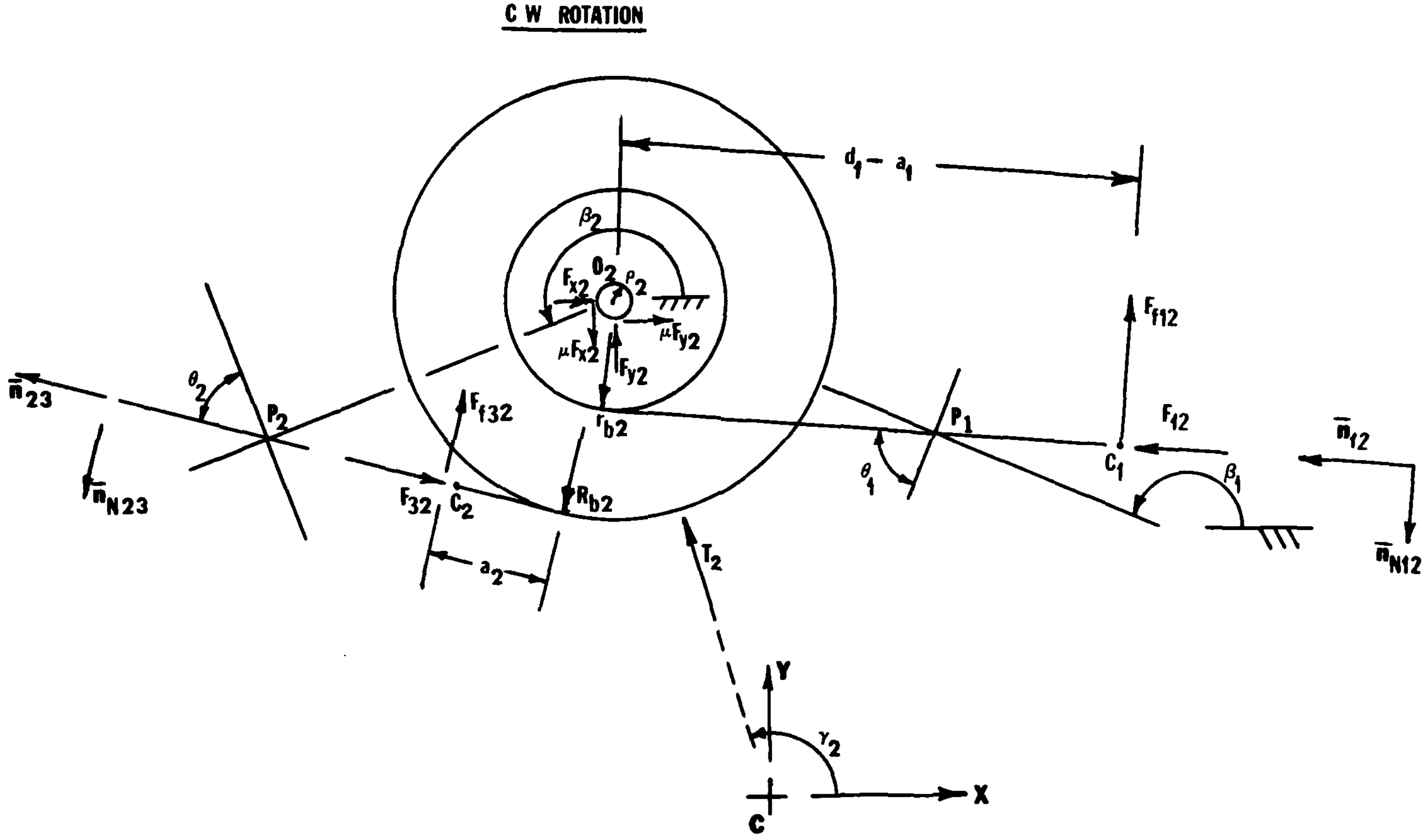

Figure B-6. Free body diagram of gear and pinion set no. 2

The unit vectors $\bar{n}_{12}$ and $\bar{n}_{N12}$ were given by equations B-64 and B-65. Hence

$$\bar{F}_{32} = -F_{23}\,\bar{n}_{23} \tag{B-93}$$

$$\bar{F}_{f32} = -s_2 \mu F_{23} \bar{n}_{N23} \tag{B-94}$$

To write the moment equation, let

$$\ddot{\phi}_2 = N_{32}\ddot{\phi} \tag{B-95}$$

where

$$N_{32} = -\frac{N_{P3}}{N_{G2}} \tag{B-96}$$

Then

$$F_{23}R_{b2} - \mu s_2 F_{23} a_2 - F_{12} r_{b2} + \mu s_1 F_{12}(d_1 - a_1) + \mu \rho_2(\tilde{F}_{x2} + \tilde{F}_{y2})$$

$$= I_2 N_{32}\ddot{\phi} \tag{B-97}$$

The bearing forces $\tilde{F}_{x2}$ and $\tilde{F}_{y2}$ are obtained from the simultaneous solution of the following component equations of the force expression B-90:

$$-F_{23}\sin(\beta_2+\theta_2) - F_{23}\mu s_2\cos(\beta_2+\theta_2) - F_{12}\sin(\beta_1-\theta_1)$$

$$+ \mu s_1 F_{12}\cos(\beta_1-\theta_1) + F_{x2} + \mu F_{y2} + T_2\cos\gamma_2 = 0 \tag{B-98}$$

and

$$F_{23}\cos(\beta_2+\theta_2) - \mu s_2 F_{23}\sin(\beta_2+\theta_2) + F_{12}\cos(\beta_1-\theta_1)$$

$$+ \mu s_1 F_{12}\sin(\beta_1-\theta_1) + F_{y2} - \mu F_{x2} + T_2\sin\gamma_2 = 0 \tag{B-99}$$

This leads to

$$\tilde{F}_{x2} = F_{23}\, A_{36} + F_{12}\, A_{37} + T_2\, A_{38} \tag{B-100}$$

$$\tilde{F}_{y2} = F_{23}\, A_{39} + F_{12}\, A_{40} + T_2\, A_{41} \tag{B-101}$$

(all signs are left positive in order to furnish positive friction moments in equation B-97) where

$$A_{36} = \left| \frac{(1-\mu^2 s_2)\sin(\beta_2+\theta_2) + \mu(1+s_2)\cos(\beta_2+\theta_2)}{1+\mu^2} \right| \tag{B-102}$$

$$A_{37} = \left| \frac{(1+\mu^2 s_1)\sin(\beta_1-\theta_1) + \mu(1-s_1)\cos(\beta_1-\theta_1)}{1+\mu^2} \right| \tag{B-103}$$

$$A_{38} = \left| \frac{\cos\gamma_2 - \mu\sin\gamma_2}{1+\mu^2} \right| \tag{B-104}$$

$$A_{39} = \left| \frac{\mu(1+s_2)\sin(\beta_2+\theta_2) - (1-\mu^2 s_2)\cos(\beta_2+\theta_2)}{1+\mu^2} \right| \tag{B-105}$$

$$A_{40} = \left| \frac{\mu(1-s_1)\sin(\beta_1-\theta_1) - (1+\mu^2 s_1)\cos(\beta_1-\theta_1)}{1+\mu^2} \right| \tag{B-106}$$

$$A_{41} = \left| \frac{\mu\cos\gamma_2 + \sin\gamma_2}{1+\mu^2} \right| \tag{B-107}$$

Substitution of equations B-100 and B-101 into the moment equation B-97 and subsequent solution for the contact force F_{23} gives

$$F_{23} = \frac{F_{12} A_{42} - T_2 A_{43} + I_2 N_{32} \ddot{\phi}}{A_{44}} \tag{B-108}$$

where

$$A_{42} = r_{b2} - \mu \left[s_1(d_1 - a_1) + \rho_2(A_{37} + A_{40}) \right] \tag{B-109}$$

$$A_{43} = \mu\rho_2(A_{38} + A_{41}) \tag{B-110}$$

$$A_{44} = R_{b2} - \mu \left[s_2 a_2 - \rho_2(A_{36} + A_{39}) \right] \tag{B-111}$$

DYNAMICS OF COMBINED SYSTEM IN COUPLED MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

In order to obtain a single differential equation for the total system in coupled motion, in terms of the escape wheel angle ϕ, an appropriate expression for the contact force F_{23}, which also contains the contribution of the rotor, must be substituted into equation B-56.

Thus, first substitute equation B-81 for F_{12} into equation B-108, which is the above expression for F_{23}:

$$F_{23} = \frac{1}{A_{44}} \left[\frac{-A_{42}A_{32}}{A_{31}} - T_2 A_{43} - \frac{A_{42}A_{33}}{A_{31}} N_{31}\dot{\phi} - \frac{A_{42}A_{34}}{A_{31}} N_{31}^2 \dot{\phi}^2 \right.$$

$$\left. - \frac{A_{42}A_{35}}{A_{31}} \sin(\phi_{1C} + N_{31}\phi_T) + \left(I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}\right)\ddot{\phi} \right] \tag{B-112}$$

Now equation B-112 is substituted into equation B-56, and the final differential equation of coupled motion results

$$A_{45}\ddot{\phi} + A_{46}\dot{\phi}^2 + A_{47}\dot{\phi}$$

$$= A_{48} - A_{49}\sin(\phi_{1C}+N_{31}\phi_T) + A_{50}\sin(\gamma_P' - \psi - \psi_C) \qquad \text{(B-113)}$$

where

$$A_{45} = I_3A_{18} + I_{PR}A_{17}U - \frac{A_{15}A_{18}}{A_{44}}\left(I_2N_{32} - \frac{A_{42}}{A_{31}} I_{1R}N_{31}\right) \qquad \text{(B-114)}$$

$$A_{46} = I_{PR}A_{17}V + A_{17}A_{21}U^2 + \frac{A_{15}A_{18}A_{34}A_{42}}{A_{31}A_{44}} N_{31}^2 \qquad \text{(B-115)}$$

$$A_{47} = 2\frac{\omega^2}{|\omega|} A_{17}A_{20}U + \frac{A_{15}A_{18}A_{33}A_{42}}{A_{31}A_{44}} N_{31} \qquad \text{(B-116)}$$

$$A_{48} = -\frac{A_{15}A_{18}A_{32}A_{42}}{A_{31}A_{44}} - \frac{A_{15}A_{18}A_{43}}{A_{44}} T_2 - A_{16}A_{18}T_3 - \omega^2 A_{17}A_{19} \qquad \text{(B-117)}$$

$$A_{49} = \frac{A_{15}A_{18}A_{35}A_{42}}{A_{31}A_{44}} \qquad \text{(B-118)}$$

$$A_{50} = m_P r_{CP}\, \mathcal{R}_4 A_{17}\omega^2 \qquad \text{(B-119)}$$

CONTACT FORCE EQUATIONS FOR COUPLED MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

The contact force F_{23} is given by equation B-112

$$F_{23} = \frac{1}{A_{31}} \left[\frac{-A_{32}A_{42}}{A_{31}} - T_2 A_{43} - \frac{A_{33}A_{42}}{A_{31}} N_{31}\dot{\phi} - \frac{A_{42}A_{34}}{A_{31}} N_{31}^2 \dot{\phi}^2 \right.$$

$$\left. - \frac{A_{35}A_{42}}{A_{31}} \sin(\phi_{1C} + N_{31}\phi_T) + \left(I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}\right)\ddot{\phi} \right] \qquad \text{(B-120)}$$

The contact force F_{12} is found with the help of equation B-108

$$F_{12} = \frac{F_{23}\,A_{44} + T_2\,A_{43} - I_2\,N_{32}\,\ddot{\phi}}{A_{42}} \qquad \text{(B-121)}$$

The contact force P_n is given by equation B-46

$$P_n = \frac{-I_3\,\ddot{\phi} + F_{23}\,A_{15} - T_3\,A_{16}}{A_{17}} \qquad \text{(B-122)}$$

If this force is desired in terms of the pallet variable ψ, equation A-91 must be used with the understanding that it now has the following form:

$$P_n = \frac{I_{PR}\ddot{\psi} + A_{21}\dot{\psi}^2 + 2\,\frac{\omega^2}{|\omega|} A_{20}\dot{\psi} + \omega^2 A_{19} - m_p r_{CP}\, \mathcal{R}_4 \omega^2 \sin(\gamma_p' - \psi - \psi_C)}{A_{18}} \qquad \text{(B-123)}$$

where $\mathcal{R}_4$ is used, together with γ_p' as defined earlier in this appendix. As stated previously, all other parameters may be taken from appendix A.

DIFFERENTIAL EQUATIONS FOR FREE MOTION
(APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6)

Free Motion of Pallet

Let $P_n = 0$ in equation B-123. After some rearrangement, the free motion differential equation for the pallet becomes

$$A_{51}\ddot{\psi} + A_{21}\dot{\psi}^2 + A_{52}\dot{\psi} = -A_{53} + A_{54}\sin(\gamma_p' - \psi - \psi_C) \qquad \text{(B-124)}$$

where

$$A_{51} = I_{PR} \qquad \text{(B-125)}$$

$$A_{52} = 2\frac{\omega^2}{|\omega|} A_{20} \qquad \text{(B-126)}$$

$$A_{53} = \omega^2 A_{19} \qquad \text{(B-127)}$$

$$A_{54} = \omega^2 m_p r_{CP} \mathcal{R}_4 \qquad \text{(B-128)}$$

(Again, the angle γ_p' is defined for both configurations by eq B-14 and B-26.)

Free Motion of the Escape Wheel, Gear Train, Rotor System

By setting $P_n = 0$ in equation B-46, the differential equation of the system without the pallet is obtained. This leads to

$$I_3 \ddot{\phi} = A_{15} F_{23} - T_3 A_{16} \qquad \text{(B-129)}$$

Equation B-112 is then substituted into the above for F_{23}. The resulting differential equation is given by

$$A_{55}\ddot{\phi} + A_{56}\dot{\phi}^2 + A_{57}\dot{\phi} = A_{58} - A_{59}\sin(\phi_{IC} + N_{31}\phi_T) \tag{B-130}$$

where

$$A_{55} = I_3 - \frac{A_{15}}{A_{44}} N_{32} I_2 + \frac{A_{15}A_{42}}{A_{31}A_{44}} N_{31} I_{1R} \tag{B-131}$$

$$A_{56} = \frac{A_{15}A_{34}A_{42}}{A_{31}A_{44}} N_{31}^2 \tag{B-132}$$

$$A_{57} = \frac{A_{15}A_{33}A_{42}}{A_{31}A_{44}} N_{31} \tag{B-133}$$

$$A_{58} = -A_{16}T_3 - \frac{A_{15}A_{43}}{A_{44}} T_2 - \frac{A_{15}A_{32}A_{42}}{A_{31}A_{44}} \tag{B-134}$$

$$A_{59} = \frac{A_{15}A_{35}A_{42}}{A_{31}A_{44}} \tag{B-135}$$

CONTACT FORCE EQUATIONS FOR FREE MOTION (*APPLICABLE TO BOTH CONFIGURATIONS WITH APPROPRIATE s_6*)

Equation B-129 may be solved for the free motion contact force F_{F23}, once $\ddot{\phi}$ is known

$$F_{F23} = \frac{I_3\,\ddot{\phi} + T_3 A_{16}}{A_{15}} \tag{B-136}$$

Equation B-108, which was derived from the force and moment equations of gear and pinion set no. 2, may be modified to obtain the free motion contact force F_{F12}

$$F_{F12} = \frac{F_{F23} A_{44} + T_2 A_{43} - I_2 N_{32}\,\ddot{\phi}}{A_{42}} \tag{B-137}$$

It must be understood that, both in equations B-136 and B-137, the angular acceleration of free motion $\ddot{\phi}$, as obtained from the solution of equation B-130, is used.

CHANGES IN IMPACT EXPRESSIONS
(APPLICABLE TO BOTH CONFIGURATIONS)

Both the rotor and gear and pinion set no. 2 must be referred to the escape wheel shaft. Thus, similar to equation A-212, appendix A

$$I_{STOT} = I_3 + I_2 N_{32}^2 + I_1 N_{31}^2 \qquad (B\text{-}138)$$

See equations B-59 and B-96 for the above transmission ratios.

APPENDIX C

COMPUTER PROGRAM SANDA3

```
PROGRAM SANDA3      74/74    OPT=1                        FTN 4.8+508         08/07/81   13.32.47         PAGE      1

            PROGRAM SANDA3(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
            COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
           1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
           2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
           3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
           43,GAMMA2,GAM43P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
           5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
           6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
           7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
           8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
            COMMON /ZETA/ PSI,TIME,G,DPSI,GP
            DIMENSION AUX(8,2), AUX2(8,4), PRMT(5), PHI(2), DPHI(2), X(4), DX(
           14)
            REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,LAMBDA,K,N41,N42,N43,J1,J2,J3,N
           1G1,NG2,NG3,NP2,NP3,NP4,MU,MU1
            EXTERNAL FCT,OUTP,FCTF,OUTPF
C
C           READ IN AND WRITE DATA
C
            READ (5,22) A,B,C,R,ALPHA,CONFIG
            WRITE (6,23) A,B,C,R,ALPHA,CONFIG
            READ (5,24) EREST,LAMBDA,DELTA
            WRITE (6,25) EREST,LAMBDA,DELTA
            READ (5,26) M1,M2,M3,M4,MP
            WRITE (6,27) M1,M2,M3,M4,MP
            READ (5,26) I1,I2,I3,I4,IP
            WRITE (6,28) I1,I2,I3,I4,IP
            READ (5,29) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MU1
            WRITE (6,30) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MU1
            READ (5,31) PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRP1,CA
           1PRP2,CAPRP3,RP2,RP3,RP4,THETA1,THETA2,THETA3
            WRITE (6,35) PSUBD1,PSUBD2,PSUBD3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRP1,C
           1APRP2,CAPRP3,RP2,RP3,RP4,THETA1,THETA2,THETA3
            READ (5,22) R1,R2,R3,R4,R5
            WRITE (6,36) R1,R2,R3,R4,R5
            READ (5,32) RHO1,RHO2,RHO3,RHO4
            WRITE (6,37) RHO1,RHO2,RHO3,RHO4
            READ (5,33) CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4
            WRITE (6,38) CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4
            READ (5,33) CAPRO1,CAPRO2,CAPRO3,RO2,RO3,RO4
            WRITE (6,39) CAPRO1,CAPRO2,CAPRO3,RO2,RO3,RO4
            READ (5,34) J1,J2,J3
            WRITE (6,40) J1,J2,J3
C
C           INITIALIZATION OF PARAMETERS AND CONVERSION TO RADIANS
C
            TIME=0.
            PHITOT=0.
            PHIPR=PHID
            DPHI2=0.
            DPSI2=0.
            F34MAX=0.
            F23MAX=0.
            F12MAX=0.
            FF34MAX=0.
            FF23MAX=0.
            FF12MAX=0.
```

Computer program SANDA3 (cont)


```
      PNMAX=0.
      PI=3.14159
      ZZ=PI/180.
      OMEGA=RPM*2.*PI/60.
      OM2=OMEGA*OMEGA
      PHI1C=PHI1CD*ZZ
      PSICC=PSICCD*ZZ
      PSIC=PSICC
      ALPHR=ALPHA*ZZ
C
C     DETERMINATION OF SIGNUM FUNCTION S6
C
      IF (CONFIG.EQ.1.) S6=1.
      IF (CONFIG.EQ.2.) S6=-1.
C
C     COMPUTATION OF GEAR RATIOS
C
      N41=-NP2*NP3*NP4/(NG1*NG2*NG3)
      N42=NP3*NP4/(NG2*NG3)
      N43=-NP4/NG3
C
C     COMPUTATION OF GAMMAS AND BETAS
C
      GAMMA2=S6*ACOS((R1*R1+R2*R2-(CAPRP1+RP2)**2)/(2.*R1*R2))
      GAMA3P=ACOS((R2*R2+R3*R3-(CAPRP2+RP3)**2)/(2.*R2*R3))
      GAMMA3=GAMMA2+S6*GAMA3P
      GAMA4P=ACOS((R3*R3+R4*R4-(CAPRP3+RP4)**2)/(2.*R3*R4))
      GAMMA4=GAMMA3+S6*GAMA4P
      GAMA5P=ACOS((R4*R4+R5*R5-A*A)/(2.*R4*R5))
      GAMMA5=GAMMA4+S6*GAMA5P
      GAMMA2D=GAMMA2/ZZ
      GAMMA3D=GAMMA3/ZZ
      GAMMA4D=GAMMA4/ZZ
      GAMMA5D=GAMMA5/ZZ
      DELTA2=ACOS(((CAPRP1+RP2)**2+R1*R1-R2*R2)/(2.*R1*(CAPRP1+RP2)))
      DELTA3=ACOS(((CAPRP2+RP3)**2+R2*R2-R3*R3)/(2.*R2*(CAPRP2+RP3)))
      DELTA4=ACOS(((CAPRP3+RP4)**2+R3*R3-R4*R4)/(2.*R3*(CAPRP3+RP4)))
      DELTA5=ACOS((A*A+R4*R4-R5*R5)/(2.*A*R4))
      BETA1=PI-S6*DELTA2
      BETA2=GAMMA2+PI-S6*DELTA3
      BETA3=GAMMA3+PI-S6*DELTA4
      BETA4=GAMMA4+PI-S6*DELTA5
      BETA1D=BETA1/ZZ
      BETA2D=BETA2/ZZ
      BETA3D=BETA3/ZZ
      BETA4D=BETA4/ZZ
      IF (CONFIG.EQ.1.) GAMAPP=DELTA5+GAMA5P
      IF (CONFIG.EQ.2.) GAMAPP=2.*PI-DELTA5-GAMA5P
      WRITE (6,41) BETA1D,BETA2D,BETA3D,BETA4D,GAMMA2D,GAMMA3D,GAMMA4D,G
     1AMMA5D
C
C     CONVERSION OF PRESSURE ANGLES TO RADIANS
C
      THETA1=THETA1*ZZ
      THETA2=THETA2*ZZ
      THETA3=THETA3*ZZ
C
```

```
      C     COMPUTATION OF CENTRIFUGAL FORCES
      C
            T2=M2*R2*OM2
            T3=M3*R3*OM2
            T4=M4*R4*OM2
      C
      C     DETERMINATION OF GEAR TRAIN CONSTANTS
      C
            TEST1=TAN(THETA1)
            TEST2=TAN(THETA2)
            TEST3=TAN(THETA3)
            D1=(CAPRB1+RB2)*TAN(THETA1)
            D2=(CAPRB2+RB3)*TAN(THETA2)
            D3=(CAPRB3+RB4)*TAN(THETA3)
      C
      C     DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS
      C
            CALL ALFA (CAPRB1,RB2,THETA1,CAPRO1,RO2,AL1IN,AL1FIN)
            CALL ALFA (CAPRB2,RB3,THETA2,CAPRO2,RO3,AL2IN,AL2FIN)
            CALL ALFA (CAPRB3,RB4,THETA3,CAPRO3,RO4,AL3IN,AL3FIN)
      C
      C     INITIALIZATION OF ALPHAS
      C
            ALPHA1=AL1IN+(AL1FIN-AL1IN)*J1
            ALPHA2=AL2IN+(AL2FIN-AL2IN)*J2
            ALPHA3=AL3IN+(AL3FIN-AL3IN)*J3
      C
      C     DATA FOR RUNGE KUTTA
      C
            PRMT(2)=3.
            PRMT(4)=.01
            NDIM=2
            NDIM2=4
            PHI(1)=PHID*ZZ
            PHI(2)=0.
      C
      C     COUPLED MOTION
      C
          1 PRMT(1)=TIME
            PRMT(3)=.00001
            DPHI(1)=.5
            DPHI(2)=.5
            IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 2
            WRITE (6,42)
          2 CALL RKGS (PRMT,PHI,DPHI,NDIM,IHLF,FCT,OUTP,AUX)
            IF (PHITOT.GE.PHICUTD) GO TO 21
      C
      C     TEST FOR ENTRANCE OR EXIT ACTION
      C
            IF (G.LE.0.) GO TO 5
            PHID=PHI(1)/ZZ
            IF (PHID.GE.135.00.AND.PHID.LE.160.) GO TO 3
            GO TO 4
          3 PHI(1)=PHI(1)+DELTA*ZZ
            PHIPR=PHI(1)/ZZ
            PSI=PSI+2.*PI-LAMBDA*ZZ
            PSIC=PSICC+LAMBDA*ZZ
```

```
      GO TO 5
    4 PHI(1)=PHI(1)-DELTA*ZZ*2.
      PHIPR=PHI(1)/ZZ
      PSI=PSI-2.*PI+LAMBDA*ZZ
      PSIC=PSICC
C
C     FREE MOTION
C
    5 PRMT(1)=TIME
      X(1)=PHI(1)
      X(2)=PHI(2)
      X(3)=PSI
      X(4)=DPSI
      DX(1)=.25
      DX(2)=.25
      DX(3)=.25
      DX(4)=.25
      PRMT(3)=.00001
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 6
      WRITE (6,43)
    6 CALL RKGS (PRMT,X,DX,NDIM2,IHLF,FCTF,OUTPF,AUX2)
      IF (PHITOT.GE.PHICUTD) GO TO 21
      PHI(1)=X(1)
      PHI(2)=X(2)
      H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
     1PHI(1)-ALPHR)
      GONE=(-H+SQRT(H*H-4.*K))/2.
      GTWO=(-H-SQRT(H*H-4.*K))/2.
      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 7
      G=GTWO
      GO TO 8
    7 G=GONE
    8 PHID=PHI(1)/ZZ
      IF (GP.LT.0.) GO TO 11
      IF (PHID.GE.135.0.AND.PHID.LE.160.) GO TO 9
      GO TO 10
    9 PHI(1)=PHI(1)+DELTA*ZZ
      PHIPR=PHI(1)/ZZ
      PSI=PSI+2.*PI-LAMBDA*ZZ
      PSIC=PSICC+LAMBDA*ZZ
      GO TO 5
   10 PHI(1)=PHI(1)-DELTA*ZZ*2.
      PHIPR=PHI(1)/ZZ
      PSI=PSI-2.*PI+LAMBDA*ZZ
      PSIC=PSICC
      GO TO 5
   11 IF (PHID.LE.160.0) GO TO 13
C
C     EXIT ACTION
C
C     COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION
C
      AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
```

Computer program SANDA3 (cont)


```
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 12
      WRITE (6,44) VP,VS
C
C     EXIT ACTION TEST
C
   12 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 15
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
C
C     COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
C
   13 AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 14
      WRITE (6,44) VP,VS
C
C     ENTRANCE ACTION
C
   14 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15
      IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 15
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
C
C     IMPACT
C
   15 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)
      H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
      K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*
     1SIN(PHI(1)-ALPHR)
      GONE=(-H+SQRT(H**2-4.*K))/2.
      GTWO=(-H-SQRT(H**2-4.*K))/2.
      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 16
      G=GTWO
      GO TO 17
   16 G=GONE
   17 IF (TIME.GT.5.0) GO TO 21
C
C
C     TEST FOR EXIT ACTION
C
      PHID=PHI(1)/ZZ
      IF (PHID.LE.160.0) GO TO 19
C
C     EXIT ACTION
C
C     COMPUTATION OF VELOCITIES VP AND VS FOR BOTTOM ACTION
```

```
      AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 18
      WRITE (6,44) VP,VS
   18 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C     EXIT ACTION TESTS
C
      IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
C
C     COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
C
   19 AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 20
      WRITE (6,44) VP,VS
   20 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C     ENTRANCE ACTION TESTS
C
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
   21 TURNS=TIME*RPM/60.
      WRITE (6,45) F34MAX,F23MAX,F12MAX,FF34MAX,FF23MAX,FF12MAX,PNMAX,
     1TURNS
      STOP
C
C
C
   22 FORMAT (6F10.5)
   23 FORMAT (1H1,5X,2HA=,F13.5,5X,2HB=,F13.5,5X,2HC=,F13.5,5X,2HR=,F13.
     15,5X,6HALPHA=,F9.4,5X,14HCONFIGURATION=,F3.0/)
   24 FORMAT (3F10.5)
   25 FORMAT (1H ,5X,6HEREST=,F5.2,3X,7HLAMBDA=,F8.3,3X,6HDELTA=,F8.3/)
   26 FORMAT (5E12.5)
   27 FORMAT (1H ,5X,4HM1 =,E15.5,3X,4HM2 =,E15.5,3X,4HM3 =,E15.5,3X,4HM
     14 =,E15.5,3X,4HMP =,E15.5/)
   28 FORMAT (1H ,5X,4HI1 =,E15.5,3X,4HI2 =,E15.5,3X,4HI3 =,E15.5,3X,4HI
     14 =,E15.5,3X,4HIP =,E15.5/)
   29 FORMAT (7F10.4/3F10.4)
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Computer program SANDA3 (cont)


```
   30 FORMAT (6X,5HRC1 =,F7.4,3X,5HRCP =,F7.4,3X,6HRHOP =,F7.4,3X,5HRPM   A 343
     1=,F6.0,3X,8HPHI1CD =,F9.4,3X,8HPSICCD =,F9.4,3X,6HPHID =,F9.4//6X,  A 344
     29HPHICUTD =,F6.0//6X,4HMU =,F4.2,3X,5HMU1 =,F4.2/)                  A 345
   31 FORMAT (3F10.4/6F10.0/6F10.5/3F10.4)                                 A 346
   32 FORMAT (5F10.4)                                                      A 347
   33 FORMAT (6F10.5)                                                      A 348
   34 FORMAT (3F10.2)                                                      A 349
   35 FORMAT (1H ,5X,8HPSUBD1 =,F5.1,3X,8HPSUBD2 =,F5.1,3X,8HPSUBD3 =,F5  A 350
     1.1//6X,5HNG1 =,F4.0,3X,5HNG2 =,F4.0,3X,5HNG3 =,F4.0,3X,5HNP2 =,F4.  A 351
     20,3X,5HNP3 =,F4.0,3X,5HNP4 =,F4.0//6X,8HCAPRP1 =,F8.5,3X,8HCAPRP2   A 352
     3=,F8.5,3X,8HCAPRP3 =,F8.5//6X,5HRP2 =,F8.5,3X,5HRP3 =,F8.5,3X,5HRP  A 353
     44 =,F8.5//6X,8HTHETA1 =,F8.3,3X,8HTHETA2 =,F8.3,3X,8HTHETA3 =,F8.3  A 354
     5/)                                                                  A 355
   36 FORMAT (6X,4HR1 =,F7.5,3X,4HR2 =,F7.5,3X,4HR3 =,F7.5,3X,4HR4 =,F7.  A 356
     15,3X,4HR5 =,F7.5/)                                                  A 357
   37 FORMAT (6X,6HRHO1 =,F7.5,3X,6HRHO2 =,F7.5,3X,6HRHO3 =,F7.5,3X,6HRH  A 358
     104 =,F7.5/)                                                         A 359
   38 FORMAT (6X,8HCAPRB1 =,F7.5,3X,8HCAPRB2 =,F7.5,3X,8HCAPRB3 =,F7.5,3  A 360
     1X,5HRB2 =,F7.5,3X,5HRB3 =,F7.5,3X,5HRB4 =,F7.5/)                    A 361
   39 FORMAT (6X,8HCAPRO1 =,F7.5,3X,8HCAPRO2 =,F7.5,3X,8HCAPRO3 =,F7.5,3  A 362
     1X,5HRO2 =,F7.5,3X,5HRO3 =,F7.5,3X,5HRO4 =,F7.5/)                    A 363
   40 FORMAT (1H0,5X,4HJ1 =,F4.2,3X,4HJ2 =,F4.2,3X,4HJ3 =,F4.2/)          A 364
   41 FORMAT (6X,8HBETA1D =,F7.2,3X,8HBETA2D =,F7.2,3X,8HBETA3D =,F7.2,3  A 365
     1X,8HBETA4D =,F7.2//6X,9HGAMMA2D =,F7.2,3X,9HGAMMA3D =,F7.2,3X,9HGA  A 366
     2MMA4D =,F7.2,3X,9HGAMMA5D =,F7.2/)                                  A 367
   42 FORMAT (1H0,5X,14HCOUPLED MOTION)                                    A 368
   43 FORMAT (1H0,5X,11HFREE MOTION//)                                     A 369
   44 FORMAT (4HOVP=,F8.3,3X,3HVS=,F8.3)                                   A 370
   45 FORMAT (1H0,6X,*F34MAX =*,F6.2/1H0,6X,*F23MAX =*,F6.2/1H0,6X,*F12   A 371
     1MAX =*,F6.2/1H0,6X,*FF34MAX =*,F6.2/1H0,6X,*FF23MAX =*,F6.2/1H0,6X  A 372
     2*FF12MAX =*,F6.2/1H0,6X,*PNMAX =*,F6.2/1H0,6X,*TURNS =*,F6.2)       A 373
      END                                                                 A 374-
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Computer program SANDA3 (cont)

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SUBROUTINE IMPACT      74/74    OPT=1                    FTN 4.8+508         08/07/81   13.32.47        PAGE      1

      SUBROUTINE IMPACT (PHI,DPHI,PSI,DPSI)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
     1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
     2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
     3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
     43,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
     5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
     6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
     7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
     8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      REAL I1,I2,I3,I4,IP,LAMBDA,N41,N42,N43,ISTOT,K
      ISTOT=I4+I1*N41*N41+I2*N42*N42+I3*N43*N43
      H=2.*(B*COS(ALPHR)+A*COS(PHI-ALPHR))
      K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI)-2.*A*R*SIN
     1(PHI-ALPHR)
      GONE=(-H+SQRT(H**2-4.*K))/2.
      GTWO=(-H-SQRT(H**2-4.*K))/2.
      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1
      G=GTWO
      GO TO 2
    1 G=GONE
    2 AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI-ALPHR-PSI)
      DPHIIN=DPHI
      DPHI=(IP*AONE*DPSI+ISTOT*DONE*DPHI+IP*AONE*EREST/DONE*(DPSI*DONE-D
     1PHI*AONE))/(IP*AONE**2/DONE+ISTOT*DONE)
      DPSI=(DPHI*AONE-EREST*(DPSI*DONE-DPHIIN*AONE))/DONE
      PHID=PHI/ZZ
      PSID=PSI/ZZ
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 3
      WRITE (6,4)
      WRITE (6,5) PHID,DPHI,PSID,DPSI,PHITOT
    3 RETURN
C
C
C
    4 FORMAT (1H0,5X,6HIMPACT)
    5 FORMAT (1H0,18X,4HPHI=,F8.3,3X,7HPHIDOT=,F8.3,3X,4HPSI=,F8.3,3X,7H
     1PSIDOT=,F8.3,3X,8HPHITOT =,F8.3)
      END
```

Computer program SANDA3 (cont)

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SUBROUTINE FCT          74/74    OPT=1                        FTN 4.8+508          08/07/81  13.32.47          PAGE     1

      SUBROUTINE FCT (T,PHI,DPHI)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
     1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
     2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
     3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
     43,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
     5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
     6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
     7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
     8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      DIMENSION PHI(2), DPHI(2)
      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
      PHID=PHI(1)/ZZ
      DELPHI=PHID-PHIPR
      PHIT=(PHITOT+DELPHI)*ZZ
      IN=1
      CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
     1,DONE,U,V,Z)
      CALL IN3 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
     12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
     2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
     330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
     43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
      IF (DPSI*DPSI2.GE.0.) IPR=IP+AA22
      IF (DPSI*DPSI2.LT.0.) IPR=IP-AA22
      IF (PHI(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (PHI(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      AA54=I4+AA18+IPR*AA17*U-N41*I1R*AA15*AA18*AA44*AA53/(AA31*AA42*AA5
     11)+N42*I2*AA15*AA18*AA44/(AA42*AA51)-N43*I3*AA15*AA18/AA42
      AA55=IPR*AA17*V+AA17*AA21*Z*Z+N41*N41*AA15*AA18*AA34*AA44*AA53/(AA
     131*AA42*AA51)
      AA56=2.*OM2/ABS(OMEGA)*AA17*AA20*Z-N41*AA15*AA18*AA33*AA44*AA53/(A
     1A31*AA42*AA51)
      AA57=-AA16*AA18*T4-T3*AA15*AA18*AA43/AA42-T2*AA15*AA18*AA44*AA52/(
     1AA42*AA51)-AA15*AA18*AA32*AA44*AA53/(AA31*AA42*AA51)-AA17*OM2*AA19
      AA58=AA17*MP*RCP*R5*OM2
      AA59=AA15*AA18*AA35*AA44*AA53/(AA31*AA42*AA51)
      DPHI(1)=PHI(2)
      DPHI(2)=(-AA55*PHI(2)*PHI(2)-AA56*PHI(2)+AA57+AA58*SIN(GAMAPP-PSI-
     1PSIC)+AA59*SIN(PHI1C+N41*(PHITOT*ZZ+PHI(1)-PHIPR*ZZ)))/AA54
      RETURN
      END
```

```
      SUBROUTINE OUTP (T,PHI,DPHI,IHLF,NDIM,PRMT)
      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
      DIMENSION PHI(2), DPHI(2), PRMT(5)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
     1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
     2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
     3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
     43,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
     5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
     6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
     7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
     8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
      PHID=PHI(1)/ZZ
      DELPHI=PHID-PHIPR
      PHIPR=PHID
      PHITOT=PHITOT+DELPHI
      PHIT=PHITOT*ZZ
      IN=0
      CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
     1,DONE,U,V,Z)
      CALL IN3 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
     12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
     2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
     330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
     43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
      IF (DPSI*DPSI2.GE.0.) IPR=IP+AA22
      IF (DPSI*DPSI2.LT.0.) IPR=IP-AA22
      IF (PHI(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (PHI(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      AA54=I4*AA18+IPR*AA17*U-N41*I1R*AA15*AA18*AA44*AA53/(AA31*AA42*AA5
     11)+N42*I2*AA15*AA18*AA44/(AA42*AA51)-N43*I3*AA15*AA18/AA42
      AA55=IPR*AA17*V+AA17*AA21*Z*Z+N41*N41*AA15*AA18*AA34*AA44*AA53/(AA
     131*AA42*AA51)
      AA56=2.*OM2/ABS(OMEGA)*AA17*AA20*Z-N41*AA15*AA18*AA33*AA44*AA53/(A
     1A31*AA42*AA51)
      AA57=-AA16*AA18*T4-T3*AA15*AA18*AA43/AA42-T2*AA15*AA18*AA44*AA52/(
     1AA42*AA51)-AA15*AA18*AA32*AA44*AA53/(AA31*AA42*AA51)-AA17*OM2*AA19
      AA58=AA17*MP*RCP*R5*OM2
      AA59=AA15*AA18*AA35*AA44*AA53/(AA31*AA42*AA51)
      DPHI2=(-AA55*PHI(2)*PHI(2)-AA56*PHI(2)+AA57+AA58*SIN(GAMAPP-PSI-PS
     1IC)+AA59*SIN(PHI1C+N41*PHIT))/AA54
      DPSI2=U*DPHI2+V*PHI(2)*PHI(2)
C
C     COMPUTATION OF CONTACT FORCES
C
      F34=(-AA32*AA44*AA53-AA31*AA44*AA52*T2-AA31*AA43*AA51*T3+AA35*AA44
     1*AA53*SIN(PHI1C+N41*PHIT)+AA33*AA44*AA53*N41*PHI(2)-AA34*AA44*AA53
     2*N41*N41*PHI(2)*PHI(2)+(AA44*AA53*I1R*N41-AA31*AA44*I2*N42+AA31*AA
     351*I3*N43)*DPHI2)/(AA31*AA42*AA51)
      F23=(F34*AA42+T3*AA43-I3*N43*DPHI2)/AA44
      F12=(F23*AA51+T2*AA52+I2*N42*DPHI2)/AA53
      IF (F34.GT.F34MAX) F34MAX=F34
      IF (F23.GT.F23MAX) F23MAX=F23
      IF (F12.GT.F12MAX) F12MAX=F12
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Computer program SANDA3 (cont)


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      PN=(-I4*DPHI2+F34*AA15-T4*AA16)/AA17
      PNPSI=(IPR*DPSI2+AA21*DPSI*DPSI+2.*OM2/ABS(OMEGA)*DPSI*AA20+OM2*AA
     119-MP*RCP*R5*OM2*SIN(GAMAPP-PSI-PSIC))/AA18
      IF (PN.GT.PNMAX) PNMAX=PN
C
C     TEST FOR CONTINUATION OF COUPLED MOTION
C
      IF (.NOT.(G.LT.0..AND.PNPSI.GT.0.)) PRMT(5)=1.
C
C     WRITE OUTPUT
C
      PSID=PSI/ZZ
      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 1
      WRITE (6,2) T,PHID,PHI(2),G,GDOT,PSID,DPSI,PHITOT,F34,F23,F12,PN,P
     1NPSI,DPHI2
    1 TIME=T
      IF(PHITOT.GE.PHICUTD)PRMT(5)=1.
      RETURN
C
C
    2 FORMAT (6X,3HT =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,3HG =,
     1F6.4,3X,6HGDOT =,F6.2,3X,6HPSID =,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHI
     2TOT =,F7.2/20X,5HF34 =,F7.4,3X,5HF23 =,F7.4,3X,5HF12 =,F7.4,3X,4HP
     3N =,F7.4,3X,7HPNPSI =,F7.4,3X,7HDPHI2 =,E12.4)
      END
```

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SUBROUTINE FCTF       74/74    OPT=1                    FTN 4.8+508         08/07/81   13.32.47         PAGE      1

          SUBROUTINE FCTF (T,X,DX)
          COMMON A,B,C,R,ALPHR,FI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
         1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
         2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
         3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
         43,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
         5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
         6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
         7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
         8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
          DIMENSION X(4), DX(4)
          REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,MU,MU1,N41,N42,N43,IPR
          PHID=X(1)/ZZ
          DELPHI=PHID-PHIPR
          PHIT=(PHITOT+DELPHI)*ZZ
          IN=1
          CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
         1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
         219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
         32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
         4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
          IF (X(4)*DPSI2.GE.0.) IPR=IP+AA22
          IF (X(4)*DPSI2.LT.0.) IPR=IP-AA22
          IF (X(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
          IF (X(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
          IF (I1R.LT.0.) I1R=0.
          IF (IPR.LT.0.) IPR=0.
          IF (IPR.EQ.0.) WRITE (6,1)
          AA60=IPR
          AA61=2.*OM2*AA20/ABS(OMEGA)
          AA62=AA19*OM2
          AA63=OM2*MP*RCP*R5
          AA64=I4-AA15*AA44*AA53*N41*I1R/(AA31*AA42*AA51)+AA15*AA44*N42*I2/(
         1AA42*AA51)-AA15*N43*I3/AA42
          AA65=AA15*AA34*AA44*AA53*N41*N41/(AA31*AA42*AA51)
          AA66=AA15*AA33*AA44*AA53*N41/(AA31*AA42*AA51)
          AA67=-AA16*T4-AA15*AA43*T3/AA42-AA15*AA44*AA52*T2/(AA42*AA51)-AA15
         1*AA32*AA44*AA53/(AA31*AA42*AA51)
          AA68=AA15*AA35*AA44*AA53/(AA31*AA42*AA51)
          DX(1)=X(2)
          DX(3)=X(4)
          DX(2)=(-AA65*X(2)*X(2)+AA66*X(2)+AA67+AA68*SIN(PHI1C+N41*(PHITOT*Z
         1Z+X(1)-PHIPR*ZZ)))/AA64
          DX(4)=(-AA21*X(4)*X(4)-AA61*X(4)-AA62+AA63*SIN(GAMAPP-X(3)-PSIC))/
         1AA60
          RETURN
      C
      C
        1 FORMAT (40H0IPR EQUALS ZERO - SIMULATION TERMINATED)
          END
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Computer program SANDA3 (cont)

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SUBROUTINE OUTPF      74/74    OPT=1                        FTN 4.8+508        08/07/81   13.32.47        PAGE     1

      SUBROUTINE OUTPF (T,X,DX,IHLF,NDIM,PRMT)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
     1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
     2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
     3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
     43,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
     5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
     6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
     7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPSI2,F34MAX,F23MAX,F12MAX,
     8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      REAL M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,I1R,N41,N42,N43,MU,MU1,IPR
      DIMENSION X(4), DX(4), PRMT(5)
      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
      PHID=X(1)/ZZ
      PSID=X(3)/ZZ
      DELPHI=PHID-PHIPR
      PHITOT=PHITOT+DELPHI
      PHIT=PHITOT*ZZ
      PHIPR=PHID
      IN=0
      CALL IN3 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
     1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
     219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
     32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44,AA45
     4,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
      IF (X(4)*DPSI2.GE.0.) IPR=IP+AA22
      IF (X(4)*DPSI2.LT.0.) IPR=IP-AA22
      IF (X(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (X(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      AA60=IPR
      AA61=2.*OM2*AA20/ABS(OMEGA)
      AA62=AA19*OM2
      AA63=OM2*MP*RCP*R5
      AA64=I4-AA15*AA44*AA53*N41*I1R/(AA31*AA42*AA51)+AA15*AA44*N42*I2/(
     1AA42*AA51)-AA15*N43*I3/AA42
      AA65=AA15*AA34*AA44*AA53*N41*N41/(AA31*AA42*AA51)
      AA66=AA15*AA33*AA44*AA53*N41/(AA31*AA42*AA51)
      AA67=-AA16*T4-AA15*AA43*T3/AA42-AA15*AA44*AA52*T2/(AA42*AA51)-AA15
     1*AA32*AA44*AA53/(AA31*AA42*AA51)
      AA68=AA15*AA35*AA44*AA53/(AA31*AA42*AA51)
      PSI=X(3)
      DPSI=X(4)
      DPHI2=(-AA65*X(2)*X(2)+AA66*X(2)+AA67+AA68*SIN(PHI1C+N41*PHIT))/AA
     164
      DPSI2=(-AA21*X(4)*X(4)-AA61*X(4)-AA62+AA63*SIN(GAMAPP-X(3)-PSIC))/
     1AA60
C
C     COMPUTATION OF CONTACT FORCES
C
      FF34=(I4*DPHI2+T4*AA16)/AA15
      FF23=(FF34*AA42+T3*AA43-I3*N43*DPHI2)/AA44
      FF12=(FF23*AA51+T2*AA52+I2*N42*DPHI2)/AA53
      IF (FF34.GT.FF34MAX) FF34MAX=FF34
      IF (FF23.GT.FF23MAX) FF23MAX=FF23
      IF (FF12.GT.FF12MAX) FF12MAX=FF12
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Computer program SANDA3 (cont)

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SUBROUTINE OUTPF       74/74    OPT=1                    FTN 4.8+508        08/07/81  13.32.47        PAGE     2

      IF (PHITOT.GT.55..AND.PHITOT.LT.3500.) GO TO 1
      WRITE (6,4) T,PHID,X(2),PSID,X(4),PHITOT,FF12,FF23,FF34
    1 IF (T.EQ.TIME) GO TO 3
C
C     CHECK FOR CONTINUED FREE MOTION
C
      F=A*SIN(X(1)-ALPHR)-B*SIN(ALPHR)-C*SIN(X(1)-ALPHR-PSI)-R
      GP=C*COS(X(1)-ALPHR-PSI)-B*COS(ALPHR)-A*COS(X(1)-ALPHR)
      IF (F.GT.0.) GO TO 2
      PRMT(5)=1.
      GO TO 3
    2 IF (GP.GT.0.) PRMT(5)=1.
    3 TIME=T
       IF(PHITOT.GE.PHICUTO)PRMT(5)=1.
      RETURN
C
C
C
    4 FORMAT (6X,3HT =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI
     1=,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F7.2/20X,6HFF12 =,F7.3,3X,
     26HFF23 =,F7.3,3X,6HFF34 =,F7.3)
      END
```

Computer program SANDA3 (cont)

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SUBROUTINE KINEM       74/74    OPT=1                  FTN 4.8+508        08/07/81  13.32.47        PAGE      1

      SUBROUTINE KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BON
     1E,CONE,DONE,U,V,Z)
      DIMENSION PHI(2)
      REAL K
      PI=3.14159
      H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
     1PHI(1)-ALPHR)
      GONE=(-H+SQRT(H*H-4.*K))/2.
      GTWO=(-H-SQRT(H*H-4.*K))/2.
      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1
      G=GTWO
      GO TO 2
    1 G=GONE
    2 P=B*SIN(PHI(1))+G*SIN(PHI(1)-ALPHR)+R*COS(PHI(1)-ALPHR)
      Q=B*COS(PHI(1))+G*COS(PHI(1)-ALPHR)-R*SIN(PHI(1)-ALPHR)
      S=G+B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)
      GDOT=PHI(2)*A*P/S
      PSI=ASIN(P/C)
      IF (PSI.LT.0.) GO TO 3
      GO TO 4
    3 PSI=2.*PI-ABS(PSI)
    4 DPSI=(Q*PHI(2)+GDOT*SIN(PHI(1)-ALPHR))/(C*COS(PSI))
      AONE=B*COS(ALPHR)+G
      BONE=B*SIN(ALPHR)
      CONE=-(R+C*SIN(PHI(1)-ALPHR-PSI))
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      Z=(Q+A*P/S*SIN(PHI(1)-ALPHR))/(C*COS(PSI))
      U=(Q+SIN(PHI(1)-ALPHR)*P*A/S)/(C*COS(PSI))
      V=(Q+A*P*SIN(PHI(1)-ALPHR)/S)**2*TAN(PSI)/(C**2*(COS(PSI))**2)+(1.
     1/(C*COS(PSI)))*(2.*A*P*COS(PHI(1)-ALPHR)/S-P+2.*A**2*P*(SIN(PHI(1)
     2-ALPHR))**2/S**2+A*Q*SIN(PHI(1)-ALPHR)/S-A**2*P**2*SIN(PHI(1)-ALPH
     3R)/S**3)
      RETURN
      END
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```
      SUBROUTINE IN3 (ZZZ,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,
     1AA1,AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,
     2AA16,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,A
     3A29,AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA
     442,AA43,AA44,AA45,AA46,AA47,AA48,AA49,AA50,AA51,AA52,AA53)
      DIMENSION ZZZ(4)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,M4,MP,I1,I2,I3,I4,IP,EREST,LAM
     1BDA,DELTA,PHITOT,PHIPR,N41,N42,N43,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2
     2,TEST3,NG1,NG2,NG3,NP2,NP3,NP4,CAPRB1,CAPRB2,CAPRB3,RB2,RB3,RB4,TH
     3ETA1,THETA2,THETA3,R1,R2,R3,R4,R5,RHO1,RHO2,RHO3,RHO4,RHOP,J1,J2,J
     43,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMA5P,GAMMA5,GAMAPP,DELTA2,D
     5ELTA3,DELTA4,DELTA5,BETA1,BETA2,BETA3,BETA4,D1,D2,D3,AL1IN,AL1FIN,
     6AL2IN,AL2FIN,AL3IN,AL3FIN,ALPHA1,ALPHA2,ALPHA3,IN,T2,T3,T4,MU,MU1,
     7RCP,PSIC,S1,S2,S3,S4,S5,A1,A2,A3,DPHI2,DPS12,F34MAX,F23MAX,F12MAX,
     8FF34MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      REAL M1,M2,M3,M4,MP,MU,MU1,N41,N42,N43,I1,I1R
      PHI=ZZZ(1)
      DPHI=ZZZ(2)
      IF (DPHI.EQ.0.) GO TO 1
      MU=ABS(MU)*DPHI/ABS(DPHI)
    1 IF (IN.EQ.0) GO TO 2
C
C     UPDATE VALUES OF ALPHAS
C
      DELAL3=DELPHI*ZZ
      DELAL2=DELAL3*RB3/CAPRB2
      DELAL1=DELAL2*RB2/CAPRB1
      ALPHA1=ALPHA1+DELAL1
      ALPHA2=ALPHA2+DELAL2
      ALPHA3=ALPHA3+DELAL3
      IF (ALPHA1.GT.AL1FIN) ALPHA1=AL1IN
      IF (ALPHA2.GT.AL2FIN) ALPHA2=AL2IN
      IF (ALPHA3.GT.AL3FIN) ALPHA3=AL3IN
C
C     DETERMINATION OF SIGNUMS
C
    2 IF (ALPHA1.LT.TEST1) S1=1.
      IF (ALPHA2.LT.TEST2) S2=1.
      IF (ALPHA3.LT.TEST3) S3=1.
      IF (ALPHA1.GT.TEST1) S1=-1.
      IF (ALPHA2.GT.TEST2) S2=-1.
      IF (ALPHA3.GT.TEST3) S3=-1.
      IF (ALPHA1.EQ.TEST1) S1=0.
      IF (ALPHA2.EQ.TEST2) S2=0.
      IF (ALPHA3.EQ.TEST3) S3=0.
      IF (GDOT.NE.0.) GO TO 3
      S4=1.
      GO TO 4
    3 S4=GDOT/ABS(GDOT)
    4 IF (DPSI.NE.0.) GO TO 5
      S5=1.
      GO TO 6
    5 S5=DPSI/ABS(DPSI)
C
C     COMPUTATION OF A1, A2, AND A3
C
    6 A1=ALPHA1*CAPRB1
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Computer program SANDA3 (cont)


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      A2=ALPHA2*CAPRB2
      A3=ALPHA3*CAPRB3
      DENOM=1.+MU*MU
      DENOM1=1.+MU1*MU1
C
C     COMPUTATION OF AA1 TO AA53
C
      AA1=ABS((MU1*(S4-S5)*SIN(PHI-ALPHR)-(1.+S4*S5*MU1*MU1)*COS(PHI-ALP
     1HR))/DENOM1)
      AA2=ABS((MP*(R5*(SIN(GAMAPP)-MU1*S5*COS(GAMAPP))+RCP*(SIN(PSI+PSIC
     1)-MU1*S5*COS(PSI+PSIC))))/DENOM1)
      AA3=ABS((MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
      AA4=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
      AA5=ABS((MU1*(S4-S5)*COS(PHI-ALPHR)+(1.+S4*S5*MU1*MU1)*SIN(PHI-ALP
     1HR))/DENOM1)
      AA6=ABS((MP*(-R5*(COS(GAMAPP)+MU1*S5*SIN(GAMAPP))-RCP*(COS(PSI+PSI
     1C)+MU1*S5*SIN(PSI+PSIC))))/DENOM1)
      AA7=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)
      AA8=ABS((MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)
      AA9=ABS((-(MU1*S4-MU)*SIN(PHI-ALPHR+BETA4)+(1.+MU*MU1*S4)*COS(PHI-
     1ALPHR+BETA4))/DENOM)
      AA10=ABS((MU*(1.-S3)*SIN(BETA3+THETA3)+(1.+MU*MU*S3)*COS(BETA3+THE
     1TA3))/DENOM)
      AA11=ABS((SIN(GAMMA4)-MU*COS(GAMMA4))/DENOM)
      AA12=ABS(((1.+MU*MU1*S4)*SIN(PHI-ALPHR+BETA4)+(S4*MU1-MU)*COS(PHI-
     1ALPHR+BETA4))/DENOM)
      AA13=ABS((-(1.+MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.-S3)*COS(BETA3+TH
     1ETA3))/DENOM)
      AA14=ABS((COS(GAMMA4)+MU*SIN(GAMMA4))/DENOM)
      AA15=RB4-MU*(S3*(D3-A3)+RHO4*(AA10+AA13))
      AA16=MU*RHO4*(AA11+AA14)
      AA17=AONE+MU1*S4*BONE+MU*RHO4*(AA9+AA12)
      AA18=DONE+CONE*MU1*S4-RHOP*MU1*S5*(AA1+AA5)
      AA19=RHOP*MU1*S5*(AA2+AA6)
      AA20=RHOP*MU1*(AA3+AA7)
      AA21=S5*AA20
      AA22=RHOP*MU1*(AA4+AA8)
      AA23=ABS((MU*(1.+S1)*SIN(BETA1+THETA1)-(1.-MU*MU*S1)*COS(BETA1+THE
     1TA1))/DENOM)
      AA24=ABS((M1*(MU*R1+RC1*(MU*COS(PHI1C+N41*PHIT)+SIN(PHI1C+N41*PHIT
     1)))))/DENOM)
      AA25=ABS((M1*RC1*(MU*COS(PHI1C+PHIT*N41)+SIN(PHI1C+N41*PHIT)))/DEN
     1OM)
      AA26=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))/DEN
     1OM)
      AA27=ABS(((1.-MU*MU*S1)*SIN(BETA1+THETA1)+MU*(1.+S1)*COS(BETA1+THE
     1TA1))/DENOM)
      AA28=ABS((M1*(R1+RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))
     1)/DENOM)
      AA29=ABS((M1*RC1*(COS(PHI1C+N41*PHIT)-MU*SIN(PHI1C+N41*PHIT)))/DEN
     1OM)
      AA30=ABS((M1*RC1*(SIN(PHI1C+N41*PHIT)+MU*COS(PHI1C+N41*PHIT)))/DEN
     1OM)
      AA31=CAPRB1-MU*S1*A1+MU*RHO1*(AA23+AA27)
      AA32=OM2*RHO1*MU*(AA24+AA28)
      AA33=OM2/ABS(OMEGA)*2.*ABS(MU)*RHO1*(AA25+AA29)
      AA34=MU*RHO1*(AA25+AA29)
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SUBROUTINE IN3        74/74    OPT=1                    FTN 4.8+508        08/07/81  13.32.47        PAGE     3

      AA35=M1*R1*RC1*OM2                                                   H 115
      AA36=ABS(((1.+MU*MU*S2)*COS(BETA2-THETA2)+MU*(S2-1.)*SIN(BETA2-THE   H 116
     1TA2))/DENOM)                                                         H 117
      AA37=ABS((SIN(GAMMA3)+MU*COS(GAMMA3))/DENOM)                         H 118
      AA38=ABS(((1.-MU*MU*S3)*COS(BETA3+THETA3)-MU*(1.+S3)*SIN(BETA3+THE   H 119
     1TA3))/DENOM)                                                         H 120
      AA39=ABS(((1.+MU*MU*S2)*SIN(BETA2-THETA2)+MU*(1.-S2)*COS(BETA2-THE   H 121
     1TA2))/DENOM)                                                         H 122
      AA40=ABS((MU*SIN(GAMMA3)-COS(GAMMA3))/DENOM)                         H 123
      AA41=ABS(((1.-MU*MU*S3)*SIN(BETA3+THETA3)+MU*(1.+S3)*COS(BETA3+THE   H 124
     1TA3))/DENOM)                                                         H 125
      AA42=CAPRB3-MU*(S3*A3-RHO3*(AA38+AA41))                              H 126
      AA43=MU*RHO3*(AA37+AA40)                                             H 127
      AA44=RB3-MU*(S2*(D2-A2)+RHO3*(AA36+AA39))                            H 128
      AA45=ABS((MU*(1.-S1)*SIN(BETA1+THETA1)+(1.+MU*MU*S1)*COS(BETA1+THE   H 129
     1TA1))/DENOM)                                                         H 130
      AA46=ABS((SIN(GAMMA2)-MU*COS(GAMMA2))/DENOM)                         H 131
      AA47=ABS((MU*(1.+S2)*SIN(BETA2-THETA2)+(1.-MU*MU*S2)*COS(BETA2-THE   H 132
     1TA2))/DENOM)                                                         H 133
      AA48=ABS((MU*(1.-S1)*COS(BETA1+THETA1)-(1.+MU*MU*S1)*SIN(BETA1+THE   H 134
     1TA1))/DENOM)                                                         H 135
      AA49=ABS((MU*SIN(GAMMA2)+COS(GAMMA2))/DENOM)                         H 136
      AA50=ABS(((1.-MU*MU*S2)*SIN(BETA2-THETA2)-MU*(1.+S2)*COS(BETA2-THE   H 137
     1TA2))/DENOM)                                                         H 138
      AA51=CAPRB2-MU*(S2*A2-RHO2*(AA47+AA50))                              H 139
      AA52=MU*RHO2*(AA46+AA49)                                             H 140
      AA53=RB2-MU*(S1*(D1-A1)+RHO2*(AA45+AA48))                            H 141
      RETURN                                                               H 142
      END                                                                  H 143-
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```
A=      .20610     B=      .19200     C=      .07880     R=      .01500     ALPHA=  51.0000     CONFIGURATION= 1.

EREST= 0.00   LAMBDA= 152.144   DELTA=  30.000

N1 =      .11550E-03   M2 =      .68600E-05   M3 =      .28200E-05   M4 =      .25200E-05   MP =      .35900E-05

I1 =      .10550E-04.  I2 =      .12600E-06   I3 =      .30800E-07   I4 =      .26800E-07   IP =      .24500E-07

RC1 =  .1060   RCP = 0.0000   RHOP =  .0160   RPM =30000.   PHI1CD = 144.0000   PSICCD =   0.0000   PHID = 145.0000

PHICUTD = 3600.

MU = .15   MU1 = .15

PSUBD1 = 44.0   PSUBD2 = 65.0   PSUBD3 = 77.0

NG1 = 42.   NG2 = 27.   NG3 = 27.   NP2 =  8.   NP3 =  9.   NP4 =  9.

CAPRP1 =  .47727   CAPRP2 =  .20769   CAPRP3 =  .17532

RP2 =  .09091   RP3 =  .06923   RP4 =  .05844

THETA1 =  20.000   THETA2 =  20.000   THETA3 =  20.000

R1 = .22500   R2 = .43600   R3 = .50400   R4 = .52000   R5 = .43300

RHO1 = .06200   RHO2 = .02500   RHO3 = .01800   RHO4 = .01600

CAPRB1 = .44849   CAPRB2 = .19517   CAPRB3 = .16475   RB2 = .08543   RB3 = .06506   RB4 = .05492

CAPRO1 = .48791   CAPRO2 = .21579   CAPRO3 = .18216   RO2 = .11000   RO3 = .08089   RO4 = .06828


J1 =0.00   J2 =0.00   J3 =0.00

BETA1D = 135.82   BETA2D = 207.77   BETA3D = 247.36   BETA4D = 300.15

GAMMA2D = 114.74   GAMMA3D = 148.02   GAMMA4D = 174.35   GAMMA5D = 197.08


COUPLED MOTION
T = 0.00000   PHI = 145.00   PHIDOT =    0.00   G =-.0394     GDOT =  0.00   PSID =  62.32    PSIDOT =   0.00   PHITOT =   -.00
              F34 = 3.2663   F23 =10.6137   F12 =31.1443    PN =  .9936    PNPSI =  .9936   DPHI2 =  .2826E+06
T =  .00001   PHI = 145.00   PHIDOT =    2.83   G =-.0394     GDOT =   .61   PSID =  62.32    PSIDOT =   3.43   PHITOT =    .00
              F34 = 3.2667   F23 =10.6140   F12 =31.1441    PN =  .9938    PNPSI =  .9938   DPHI2 =  .2830E+06
T =  .00002   PHI = 145.00   PHIDOT =    5.65   G =-.0391     GDOT =  1.21   PSID =  62.32    PSIDOT =   6.87   [illegible]TOT =    .00
              F34 = 3.2667   F23 =10.6140   F12 =31.1441    PN =  .9938    PNPSI =  .9938   DPHI2 =  [illegible]E+06
T =  .00003   PHI = 145.01   PHIDOT =    8.49   G =-.0394     GDOT =  1.82   PSID =  62.33    PSIDOT =   [illegible]   [illegible]TOT =    .01
              F34 = 3.2692   F23 =10.6150   F12 =31.1435    PN =  .9947    PNPSI =  .9947   DPHI2 =  .2844E+06
T =  .00004   PHI = 145.01   PHIDOT =   11.32   G =-.0393     GDOT =  2.43   PSID =  62.33    PSIDOT =  13.76   PHITOT =    .01
              F34 = 3.2682   F23 =10.6150   F12 =31.1437    PN =  .9946    PNPSI =  .9946   DPHI2 -  .2841E+06
T =  .00005   PHI = 145.02   PHIDOT =   14.17   G =-.0393     GDOT =  3.04   PSID =  62.34    PSIDOT =  17.23   PHITOT =    .02
              F34 = 3.2708   F23 =10.6168   F12 =31.1428    PN =  .9962    PNPSI =  .9962   DPHI2 -  .28[illegible]E+06
T =  .00006   PHI = 145.03   PHIDOT =   17.03   G =-.0393     GDOT =  3.65   PSID =  62.35    PSIDOT =  20.[illegible]   PHITOT =    .03
              F34 = 3.2708   F23 =10.6170   F12 =31.1431    PN =  .9960    PNPSI =  .9960   DPHI2 =  .28[illegible]E+06
T =  .00007   PHI = 145.04   PHIDOT =   19.90   G =-.0292     GDOT =  4.27   PSID =  62.37    PSIDOT =  24.21   PHITOT =    .04
              F34 = 3.2745   F23 =10.6196   F12 =31.1420    PN =  .9983    PNPSI =  .9983   DPHI2 =  .2902E+06
T =  .00008   PHI = 145.05   PHIDOT =   22.78   G =-.0392     GDOT =  4.89   PSID =  62.38    PSIDOT =  27.73   PHITOT =    .05
              F34 = 3.2746   F23 =10.6198   F12 =31.1424    PN =  .9981    PNPSI =  .9981   DPHI2 =  .2894E+06
T =  .00009   PHI = 145.07   PHIDOT =   25.69   G =-.0391     GDOT =  5.51   PSID =  62.40    PSIDOT =  31.29   PHITOT =    .07
              F34 = 3.2794   F23 =10.6232   F12 =31.1410    PN = 1.0010    PNPSI = 1.0010   DPHI2 =  .2945E+06
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T =  .00010   PHI = 145.08   PHIDOT =  28.61   G =-.0391   GDOT =  6.14   PSID =  62.42   PSIDOT =   34.87   PHITOT =   .08
              F34 = 3.2796   F23 =10.6235   F12 =31.1416   PN = 1.0008    PNPSI = 1.0008   DPHI2 =  .2935E+06
T =  .00011   PHI = 145.10   PHIDOT =  31.57   G =-.0390   GDOT =  6.78   PSID =  62.44   PSIDOT =   38.50   PHITOT =   .10
              F34 = 3.2855   F23 =10.6276   F12 =31.1398   PN = 1.0045    PNPSI = 1.0045   DPHI2 =  .2998E+06
T =  .00012   PHI = 145.12   PHIDOT =  34.54   G =-.0390   GDOT =  7.41   PSID =  62.46   PSIDOT =   42.15   PHITOT =   .12
              F34 = 3.2857   F23 =10.6280   F12 =31.1406   PN = 1.0042    PNPSI = 1.0042   DPHI2 =  .2986E+06
T =  .00013   PHI = 145.14   PHIDOT =  37.54   G =-.0389   GDOT =  8.06   PSID =  62.49   PSIDOT =   45.87   PHITOT =   .14
              F34 = 3.2928   F23 =10.6330   F12 =31.1386   PN = 1.0085    PNPSI = 1.0085   DPHI2 =  .3061E+06
T =  .00014   PHI = 145.16   PHIDOT =  40.57   G =-.0388   GDOT =  8.71   PSID =  62.51   PSIDOT =   49.61   PHITOT =   .16
              F34 = 3.2930   F23 =10.6335   F12 =31.1395   PN = 1.0082    PNPSI = 1.0082   DPHI2 =  .3047E+06
T =  .00015   PHI = 145.18   PHIDOT =  43.64   G =-.0387   GDOT =  9.37   PSID =  62.54   PSIDOT =   53.42   PHITOT =   .18
              F34 = 3.3013   F23 =10.6393   F12 =31.1371   PN = 1.0133    PNPSI = 1.0133   DPHI2 =  .3135E+06
T =  .00016   PHI = 145.21   PHIDOT =  46.73   G =-.0386   GDOT = 10.04   PSID =  62.58   PSIDOT =   57.28   PHITOT =   .21
              F34 = 3.3016   F23 =10.6399   F12 =31.1382   PN = 1.0129    PNPSI = 1.0129   DPHI2 =  .3118E+06
T =  .00017   PHI = 145.24   PHIDOT =  49.88   G =-.0385   GDOT = 10.72   PSID =  62.61   PSIDOT =   61.20   PHITOT =   .24
              F34 = 3.3112   F23 =10.6466   F12 =31.1355   PN = 1.0188    PNPSI = 1.0188   DPHI2 =  .3218E+06
T =  .00018   PHI = 145.27   PHIDOT =  53.05   G =-.0384   GDOT = 11.40   PSID =  62.65   PSIDOT =   65.18   PHITOT =   .27
              F34 = 3.3115   F23 =10.6472   F12 =31.1368   PN = 1.0184    PNPSI = 1.0184   DPHI2 =  .3200E+06
T =  .00019   PHI = 145.30   PHIDOT =  56.28   G =-.0383   GDOT = 12.10   PSID =  62.68   PSIDOT =   69.24   PHITOT =   .30
              F34 = 3.3223   F23 =10.6548   F12 =31.1337   PN = 1.0250    PNPSI = 1.0250   DPHI2 =  .3313E+06
T =  .00020   PHI = 145.33   PHIDOT =  59.54   G =-.0382   GDOT = 12.81   PSID =  62.72   PSIDOT =   73.36   PHITOT =   .33
              F34 = 3.3227   F23 =10.6555   F12 =31.1353   PN = 1.0245    PNPSI = 1.0245   DPHI2 =  .3291E+06
T =  .00021   PHI = 145.37   PHIDOT =  62.87   G =-.0380   GDOT = 13.53   PSID =  62.77   PSIDOT =   77.57   PHITOT =   .37
              F34 = 3.3348   F23 =10.6640   F12 =31.1318   PN = 1.0320    PNPSI = 1.0320   DPHI2 =  .3418E+06
T =  .00022   PHI = 145.40   PHIDOT =  66.23   G =-.0379   GDOT = 14.25   PSID =  62.81   PSIDOT =   81.84   PHITOT =   .40
              F34 = 3.3352   F23 =10.6648   F12 =31.1335   PN = 1.0315    PNPSI = 1.0315   DPHI2 =  .3394E+06
T =  .00023   PHI = 145.44   PHIDOT =  69.66   G =-.0377   GDOT = 15.00   PSID =  62.86   PSIDOT =   86.23   PHITOT =   .44
              F34 = 3.3488   F23 =10.6743   F12 =31.1297   PN = 1.0399    PNPSI = 1.0399   DPHI2 =  .3534E+06
T =  .00024   PHI = 145.48   PHIDOT =  73.13   G =-.0376   GDOT = 15.75   PSID =  62.91   PSIDOT =   90.68   PHITOT =   .48
              F34 = 3.3492   F23 =10.6752   F12 =31.1317   PN = 1.0393    PNPSI = 1.0393   DPHI2 =  .3507E+06
T =  .00025   PHI = 145.53   PHIDOT =  76.68   G =-.0374   GDOT = 16.52   PSID =  62.97   PSIDOT =   95.25   PHITOT =   .53
              F34 = 3.3642   F23 =10.6856   F12 =31.1275   PN = 1.0485    PNPSI = 1.0485   DPHI2 =  .3662E+06
T =  .00026   PHI = 145.57   PHIDOT =  80.27   G =-.0372   GDOT = 17.30   PSID =  63.02   PSIDOT =   99.90   PHITOT =   .57
              F34 = 3.3647   F23 =10.6863   F12 =31.1296   PN = 1.0479    PNPSI = 1.0479   DPHI2 =  .3632E+06
T =  .00027   PHI = 145.62   PHIDOT =  83.94   G =-.0371   GDOT = 18.10   PSID =  63.08   PSIDOT =  104.69   PHITOT =   .62
              F34 = 3.3812   F23 =10.6981   F12 =31.1251   PN = 1.0581    PNPSI = 1.0581   DPHI2 =  .3801E+06
T =  .00028   PHI = 145.67   PHIDOT =  87.66   G =-.0369   GDOT = 18.91   PSID =  63.14   PSIDOT =  109.56   PHITOT =   .67
              F34 = 3.3818   F23 =10.6992   F12 =31.1275   PN = 1.0574    PNPSI = 1.0574   DPHI2 =  .3768E+06
T =  .00029   PHI = 145.72   PHIDOT =  91.48   G =-.0367   GDOT = 19.74   PSID =  63.21   PSIDOT =  114.57   PHITOT =   .72
              F34 = 3.3998   F23 =10.7117   F12 =31.1225   PN = 1.0686    PNPSI = 1.0686   DPHI2 =  .3952E+06
T =  .00030   PHI = 145.77   PHIDOT =  95.35   G =-.0365   GDOT = 20.58   PSID =  63.27   PSIDOT =  119.68   PHITOT =   .77
              F34 = 3.4005   F23 =10.7129   F12 =31.1251   PN = 1.0679    PNPSI = 1.0679   DPHI2 =  .3915E+06
T =  .00031   PHI = 145.83   PHIDOT =  99.32   G =-.0363   GDOT = 21.45   PSID =  63.34   PSIDOT =  124.96   PHITOT =   .83
              F34 = 3.4202   F23 =10.7265   F12 =31.1197   PN = 1.0802    PNPSI = 1.0802   DPHI2 =  .4116E+06
T =  .00032   PHI = 145.89   PHIDOT = 103.34   G =-.0361   GDOT = 22.33   PSID =  63.42   PSIDOT =  130.33   PHITOT =   .89
              F34 = 3.4210   F23 =10.7279   F12 =31.1226   PN = 1.0793    PNPSI = 1.0793   DPHI2 =  .4075E+06
T =  .00033   PHI = 145.95   PHIDOT = 107.47   G =-.0358   GDOT = 23.24   PSID =  63.49   PSIDOT =  135.89   PHITOT =   .95
              F34 = 3.4424   F23 =10.7426   F12 =31.1163   PN = 1.0928    PNPSI = 1.0928   DPHI2 =  .4292E+06
T =  .00034   PHI = 146.01   PHIDOT = 111.66   G =-.0356   GDOT = 24.15   PSID =  63.57   PSIDOT =  141.55   PHITOT =  1.01
              F34 = 3.4433   F23 =10.7441   F12 =31.1200   PN = 1.0919    PNPSI = 1.0919   DPHI2 =  .4248E+06
T =  .00035   PHI = 146.08   PHIDOT = 115.93   G =-.0354   GDOT = 25.09   PSID =  63.65   PSIDOT =  147.36   PHITOT =  1.08
              F34 = 3.1152   F23 =10.7673   F12 =31.1278   PN = 1.0914    PNPSI = 1.0914   DPHI2 =  .4209E+06
T =  .00036   PHI = 146.14   PHIDOT = 120.14   G =-.0351   GDOT = 26.02   PSID =  63.74   PSIDOT =  153.14   PHITOT =  1.14
              F34 = 3.1160   F23 =10.7689   F12 =31.1312   PN = 1.0904    PNPSI = 1.0904   DPHI2 =  .4161E+06
T =  .00037   PHI = 146.21   PHIDOT = 124.25   G =-.0348   GDOT = 26.92   PSID =  63.83   PSIDOT =  158.84   PHITOT =  1.21
              F34 = 3.1281   F23 =10.7961   F12 =31.1441   PN = 1.0849    PNPSI = 1.0849   DPHI2 =  .4032E+06
T =  .00038   PHI = 146.29   PHIDOT = 128.28   G =-.0346   GDOT = 27.81   PSID =  63.92   PSIDOT =  164.48   PHITOT =  1.29
              F34 = 3.1289   F23 =10.7978   F12 =31.1477   PN = 1.0838    PNPSI = 1.0838   DPHI2 =  .3983E+06
T =  .00039   PHI = 146.36   PHIDOT = 132.21   G =-.0343   GDOT = 28.68   PSID =  64.02   PSIDOT =  170.04   PHITOT =  1.36
              F34 = 3.1418   F23 =10.8268   F12 =31.1614   PN = 1.0779    PNPSI = 1.0779   DPHI2 =  .3846E+06
T =  .00040   PHI = 146.44   PHIDOT = 136.06   G =-.0340   GDOT = 29.53   PSID =  64.12   PSIDOT =  175.53   PHITOT =  1.44
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Computer program SANDA3 (cont)

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                 F34 = 3.1427   F23 =10.8285   F12 =31.1651   PN = 1.0767   PNPSI = 1.0767   DPHI2 =   .3795E+06
T =   .00041     PHI = 146.52   PHIDOT = 139.80   G =-.0337   GDOT = 30.36   PSID =  64.22   PSIDOT =  180.94   PHITOT =   1.52
                 F34 = 3.1503   F23 =10.8593   F12 =31.1796   PN = 1.0703   PNPSI = 1.0703   DPHI2 =   .3652E+06
T =   .00042     PHI = 146.60   PHIDOT = 143.46   G =-.0334   GDOT = 31.18   PSID =  64.32   PSIDOT =  186.27   PHITOT =   1.60
                 F34 = 3.1572   F23 =10.8611   F12 =31.1835   PN = 1.0690   PNPSI = 1.0690   DPHI2 =   .3601E+06
T =   .00043     PHI = 146.68   PHIDOT = 147.00   G =-.0331   GDOT = 31.97   PSID =  64.43   PSIDOT =  191.52   PHITOT =   1.68
                 F34 = 3.1716   F23 =10.8936   F12 =31.1987   PN = 1.0622   PNPSI = 1.0622   DPHI2 =   .3451E+06
T =   .00044     PHI = 146.77   PHIDOT = 150.46   G =-.0327   GDOT = 32.74   PSID =  64.54   PSIDOT =  196.69   PHITOT =   1.77
                 F34 = 3.1725   F23 =10.8954   F12 =31.2027   PN = 1.0608   PNPSI = 1.0608   DPHI2 =   .3399E+06
T =   .00045     PHI = 146.85   PHIDOT = 153.80   G =-.0324   GDOT = 33.49   PSID =  64.66   PSIDOT =  201.75   PHITOT =   1.85
                 F34 = 3.5290   F23 =10.9375   F12 =31.2340   PN = 1.0364   PNPSI = 1.0364   DPHI2 =   .2944E+06
T =   .00046     PHI = 146.94   PHIDOT = 157.05   G =-.0321   GDOT = 34.22   PSID =  64.78   PSIDOT =  206.74   PHITOT =   1.94
                 F34 = 3.5300   F23 =10.9393   F12 =31.2380   PN = 1.0350   PNPSI = 1.0350   DPHI2 =   .2892E+06
T =   .00047     PHI = 147.03   PHIDOT = 160.03   G =-.0317   GDOT = 34.89   PSID =  64.90   PSIDOT =  211.42   PHITOT =   2.03
                 F34 = 3.5628   F23 =10.9620   F12 =31.2237   PN = 1.0547   PNPSI = 1.0547   DPHI2 =   .3217E+06
T =   .00048     PHI = 147.13   PHIDOT = 163.10   G =-.0314   GDOT = 35.59   PSID =  65.02   PSIDOT =  216.26   PHITOT =   2.13
                 F34 = 3.5638   F23 =10.9640   F12 =31.2339   PN = 1.0531   PNPSI = 1.0531   DPHI2 =   .3159E+06
T =   .00049     PHI = 147.22   PHIDOT = 166.35   G =-.0310   GDOT = 36.32   PSID =  65.14   PSIDOT =  221.38   PHITOT =   2.22
                 F34 = 3.5982   F23 =10.9876   F12 =31.2253   PN = 1.0739   PNPSI = 1.0739   DPHI2 =   .3491E+06
T =   .00050     PHI = 147.32   PHIDOT = 169.69   G =-.0306   GDOT = 37.08   PSID =  65.27   PSIDOT =  226.68   PHITOT =   2.32
                 F34 = 3.5993   F23 =10.9897   F12 =31.2297   PN = 1.0723   PNPSI = 1.0723   DPHI2 =   .3434E+06
T =   .00051     PHI = 147.41   PHIDOT = 173.22   G =-.0303   GDOT = 37.87   PSID =  65.40   PSIDOT =  232.27   PHITOT =   2.41
                 F34 = 3.6355   F23 =11.0144   F12 =31.2207   PN = 1.0942   PNPSI = 1.0942   DPHI2 =   .3781E+06
T =   .00052     PHI = 147.51   PHIDOT = 176.84   G =-.0299   GDOT = 38.69   PSID =  65.54   PSIDOT =  238.05   PHITOT =   2.51
                 F34 = 3.6367   F23 =11.0166   F12 =31.2255   PN = 1.0925   PNPSI = 1.0925   DPHI2 =   .3719E+06
T =   .00052     PHI = 147.57   PHIDOT = 178.86   G =-.0297   GDOT = 39.15   PSID =  65.61   PSIDOT =  241.22   PHITOT =   2.57
                 F34 = 3.6319   F23 =11.0461   F12 =31.2105   PN = 1.1218   PNPSI = 1.1218   DPHI2 =   .4204E+06
T =   .00053     PHI = 147.62   PHIDOT = 180.92   G =-.0295   GDOT = 39.61   PSID =  65.68   PSIDOT =  244.48   PHITOT =   2.62
                 F34 = 3.6825   F23 =11.0473   F12 =31.2130   PN = 1.1210   PNPSI = 1.1210   DPHI2 =   .4170E+06
T =   .00053     PHI = 147.67   PHIDOT = 183.03   G =-.0293   GDOT = 40.09   PSID =  65.75   PSIDOT =  247.83   PHITOT =   2.67
                 F34 = 3.7021   F23 =11.0604   F12 =31.2082   PN = 1.1329   PNPSI = 1.1329   DPHI2 =   .4355E+06
T =   .00054     PHI = 147.72   PHIDOT = 185.16   G =-.0291   GDOT = 40.57   PSID =  65.82   PSIDOT =  251.22   PHITOT =   2.72
                 F34 = 3.7028   F23 =11.0617   F12 =31.2108   PN = 1.1321   PNPSI = 1.1321   DPHI2 =   .4320E+05
T =   .00054     PHI = 147.77   PHIDOT = 187.35   G =-.0289   GDOT = 41.07   PSID =  65.89   PSIDOT =  254.70   PHITOT =   2.77
                 F34 = 3.3528   F23 =11.0757   F12 =31.2070   PN = 1.1431   PNPSI = 1.1431   DPHI2 =   .4486E+06
T =   .00055     PHI = 147.83   PHIDOT = 189.56   G =-.0287   GDOT = 41.57   PSID =  65.96   PSIDOT =  258.23   PHITOT =   2.83
                 F34 = 3.3535   F23 =11.0770   F12 =31.2097   PN = 1.1422   PNPSI = 1.1422   DPHI2 =   .4450E+06
T =   .00055     PHI = 147.88   PHIDOT = 191.76   G =-.0285   GDOT = 42.07   PSID =  66.04   PSIDOT =  261.78   PHITOT =   2.88
                 F34 = 3.3631   F23 =11.0986   F12 =31.2198   PN = 1.1376   PNPSI = 1.1376   DPHI2 =   .4349E+06
T =   .00056     PHI = 147.94   PHIDOT = 193.94   G =-.0283   GDOT = 42.56   PSID =  66.11   PSIDOT =  265.30   PHITOT =   2.94
                 F34 = 3.3638   F23 =11.1000   F12 =31.2225   PN = 1.1366   PNPSI = 1.1366   DPHI2 =   .4313E+06
T =   .00056     PHI = 147.99   PHIDOT = 196.06   G =-.0280   GDOT = 43.04   PSID =  66.19   PSIDOT =  268.76   PHITOT =   2.99
                 F34 = 3.3561   F23 = 9.9888   F12 =31.2379   PN = 1.1260   PNPSI = 1.1260   DPHI2 =   .4113E+06
T =   .00057     PHI = 148.05   PHIDOT = 198.14   G =-.0278   GDOT = 43.51   PSID =  66.27   PSIDOT =  272.18   PHITOT =   3.05
                 F34 = 3.3567   F23 = 9.9900   F12 =31.2405   PN = 1.1251   PNPSI = 1.1251   DPHI2 =   .4077E+06
T =   .00057     PHI = 148.11   PHIDOT = 200.14   G =-.0276   GDOT = 43.97   PSID =  66.35   PSIDOT =  275.52   PHITOT =   3.11
                 F34 = 3.3471   F23 = 9.9992   F12 =31.2567   PN = 1.1137   PNPSI = 1.1137   DPHI2 =   .3865E+06
T =   .00058     PHI = 148.17   PHIDOT = 202.09   G =-.0274   GDOT = 44.42   PSID =  66.43   PSIDOT =  278.80   PHITOT =   3.17
                 F34 = 3.3478   F23 =10.0004   F12 =31.2594   PN = 1.1127   PNPSI = 1.1127   DPHI2 =   .3830E+06
T =   .00058     PHI = 148.22   PHIDOT = 203.97   G =-.0272   GDOT = 44.85   PSID =  66.51   PSIDOT =  282.00   PHITOT =   3.22
                 F34 = 3.3380   F23 =10.0098   F12 =31.2756   PN = 1.1011   PNPSI = 1.1011   DPHI2 =   .3618E+06
T =   .00059     PHI = 148.28   PHIDOT = 205.80   G =-.0269   GDOT = 45.26   PSID =  66.59   PSIDOT =  285.14   PHITOT =   3.28
                 F34 = 3.3386   F23 =10.0109   F12 =31.2783   PN = 1.1001   PNPSI = 1.1001   DPHI2 =   .3584E+06
T =   .00059     PHI = 148.34   PHIDOT = 207.55   G =-.0267   GDOT = 45.67   PSID =  66.67   PSIDOT =  288.21   PHITOT =   3.34
                 F34 = 3.3286   F23 =10.0204   F12 =31.2947   PN = 1.0883   PNPSI = 1.0883   DPHI2 =   .3371E+06
T =   .00060     PHI = 148.40   PHIDOT = 209.26   G =-.0265   GDOT = 46.06   PSID =  66.75   PSIDOT =  291.21   PHITOT =   3.40
                 F34 = 3.3292   F23 =10.0215   F12 =31.2974   PN = 1.0873   PNPSI = 1.0873   DPHI2 =   .3337E+06
T =   .00060     PHI = 148.46   PHIDOT = 210.89   G =-.0263   GDOT = 46.44   PSID =  66.84   PSIDOT =  294.13   PHITOT =   3.46
                 F34 = 3.3190   F23 =10.0311   F12 =31.3138   PN = 1.0754   PNPSI = 1.0754   DPHI2 =   .3125E+06
T =   .00061     PHI = 148.52   PHIDOT = 212.47   G =-.0260   GDOT = 46.80   PSID =  66.92   PSIDOT =  296.99   PHITOT =   3.52
                 F34 = 3.3196   F23 =10.0322   F12 =31.3165   PN = 1.0743   PNPSI = 1.0743   DPHI2 =   .3092E+06
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T = .00061  PHI = 148.58   PHIDOT = 213.98   G =-.0258   GDOT = 47.15   PSID =  67.01   PSIDOT = 299.77   PHITOT = 3.58
            F34 = 3.3092   F23 =10.0418   F12 =31.3330   PN = 1.0622    PNPSI = 1.0622  DPHI2 = .2880E+06
T = .00062  PHI = 148.64   PHIDOT = 215.44   G =-.0256   GDOT = 47.49   PSID =  67.09   PSIDOT = 302.49   PHITOT = 3.64
            F34 = 3.3098   F23 =10.0429   F12 =31.3355   PN = 1.0611    PNPSI = 1.0611  DPHI2 = .2818E+06
T = .00062  PHI = 148.71   PHIDOT = 216.83   G =-.0253   GDOT = 47.82   PSID =  67.18   PSIDOT = 305.12   PHITOT = 3.71
            F34 = 3.6576   F23 =10.0560   F12 =31.3595   PN = 1.0404    PNPSI = 1.0404  DPHI2 = .2494E+06
T = .00063  PHI = 148.77   PHIDOT = 218.05   G =-.0251   GDOT = 48.11   PSID =  67.27   PSIDOT = 307.53   PHITOT = 3.77
            F34 = 3.6582   F23 =10.0571   F12 =31.3621   PN = 1.0392    PNPSI = 1.0392  DPHI2 = .2465E+06
T = .00063  PHI = 148.83   PHIDOT = 219.30   G =-.0248   GDOT = 48.40   PSID =  67.36   PSIDOT = 309.98   PHITOT = 3.83
            F34 = 3.6576   F23 =10.0591   F12 =31.3625   PN = 1.0460    PNPSI = 1.0460  DPHI2 = .2568E+06
T = .00064  PHI = 148.[illegible]   PHIDOT = 220.55   G =-.0246   GDOT = 48.70   PSID =  67.44   PSIDOT = 312.46   PHITOT = 3.89
            F34 = 3.6[illegible]   F23 =10.0602   F12 =31.3650   PN = 1.0448    PNPSI = 1.0448  DPHI2 = .2538E+06
T = .00064  PHI = 148.[illegible]   PHIDOT = 221.83   G =-.0243   GDOT = 49.00   PSID =  67.53   PSIDOT = 314.99   PHITOT = 3.96
            F34 = 3.65[illegible]7   F23 =10.0623   F12 =31.3655   PN = 1.0517    PNPSI = 1.0517  DPHI2 = .264[illegible]E+06
T = .00065  PHI = 149.02   PHIDOT = 223.13   G =-.0241   GDOT = 49.30   PSID =  67.63   PSIDOT = 317.54   PHITOT = 4.02
            F34 = 3.6583   F23 =10.0634   F12 =31.3681   PN = 1.0505    PNPSI = 1.0505  DPHI2 = .2611E+06
T = .00065  PHI = 149.09   PHIDOT = 224.44   G =-.0239   GDOT = 49.61   PSID =  67.72   PSIDOT = 320.15   PHITOT = 4.09
            F34 = 3.6577   F23 =10.0655   F12 =31.3686   PN = 1.0575    PNPSI = 1.0575  DPHI2 = .2714E+06
T = .00066  PHI = 149.15   PHIDOT = 225.77   G =-.0236   GDOT = 49.92   PSID =  67.81   PSIDOT = 322.78   PHITOT = 4.15
            F34 = 3.6584   F23 =10.0666   F12 =31.3712   PN = 1.0563    PNPSI = 1.0563  DPHI2 = .2683E+06
T = .00066  PHI = 149.22   PHIDOT = 227.13   G =-.0234   GDOT = 50.24   PSID =  67.90   PSIDOT = 325.46   PHITOT = 4.22
            F34 = 3.6578   F23 =10.0688   F12 =31.3719   PN = 1.0633    PNPSI = 1.0633  DPHI2 = .2787E+06
T = .00067  PHI = 149.28   PHIDOT = 228.49   G =-.0231   GDOT = 50.56   PSID =  68.00   PSIDOT = 328.17   PHITOT = 4.28
            F34 = 3.6585   F23 =10.0700   F12 =31.3745   PN = 1.0620    PNPSI = 1.0620  DPHI2 = .2755E+06
T = .00067  PHI = 149.35   PHIDOT = 229.88   G =-.0228   GDOT = 50.89   PSID =  68.09   PSIDOT = 330.92   PHITOT = 4.35
            F34 = 3.6579   F23 =10.0722   F12 =31.3751   PN = 1.0691    PNPSI = 1.0691  DPHI2 = .2859E+06
T = .00068  PHI = 149.41   PHIDOT = 231.28   G =-.0226   GDOT = 51.22   PSID =  68.18   PSIDOT = 333.71   PHITOT = 4.41
            F34 = 3.6585   F23 =10.0733   F12 =31.3778   PN = 1.0679    PNPSI = 1.0679  DPHI2 = .2827E+06
T = .00068  PHI = 149.48   PHIDOT = 232.71   G =-.0223   GDOT = 51.55   PSID =  68.28   PSIDOT = 336.54   PHITOT = 4.48
            F34 = 3.6580   F23 =10.0756   F12 =31.3785   PN = 1.0750    PNPSI = 1.0750  DPHI2 = .2931E+06
T = .00069  PHI = 149.55   PHIDOT = 234.15   G =-.0221   GDOT = 51.89   PSID =  68.38   PSIDOT = 339.41   PHITOT = 4.55
            F34 = 3.6586   F23 =10.0768   F12 =31.3813   PN = 1.0737    PNPSI = 1.0737  DPHI2 = .2899E+06
T = .00069  PHI = 149.61   PHIDOT = 235.61   G =-.0218   GDOT = 52.23   PSID =  68.48   PSIDOT = 342.32   PHITOT = 4.61
            F34 = 3.6581   F23 =10.0791   F12 =31.3820   PN = 1.0810    PNPSI = 1.0810  DPHI2 = .3003E+06
T = .00070  PHI = 149.68   PHIDOT = 237.08   G =-.0216   GDOT = 52.58   PSID =  68.57   PSIDOT = 345.26   PHITOT = 4.68
            F34 = 3.6587   F23 =10.0803   F12 =31.3848   PN = 1.0797    PNPSI = 1.0797  DPHI2 = .2970E+06
T = .00070  PHI = 149.75   PHIDOT = 238.58   G =-.0213   GDOT = 52.93   PSID =  68.67   PSIDOT = 348.26   PHITOT = 4.75
            F34 = 3.2880   F23 =10.0878   F12 =31.3966   PN = 1.0738    PNPSI = 1.0738  DPHI2 = .2863E+06
T = .00071  PHI = 149.82   PHIDOT = 240.03   G =-.0210   GDOT = 53.27   PSID =  68.77   PSIDOT = 351.20   PHITOT = 4.82
            F34 = 3.2886   F23 =10.0890   F12 =31.3994   PN = 1.0724    PNPSI = 1.0724  DPHI2 = .2831E+06
T = .00071  PHI = 149.89   PHIDOT = 241.41   G =-.0208   GDOT = 53.60   PSID =  68.87   PSIDOT = 354.05   PHITOT = 4.89
            F34 = 3.2765   F23 =10.0995   F12 =31.4174   PN = 1.0589    PNPSI = 1.0589  DPHI2 = .2604E+06
T = .00072  PHI = 149.96   PHIDOT = 242.73   G =-.0205   GDOT = 53.91   PSID =  68.98   PSIDOT = 356.83   PHITOT = 4.96
            F34 = 3.2771   F23 =10.1007   F12 =31.4202   PN = 1.0575    PNPSI = 1.0575  DPHI2 = .2573E+06
T = .00072  PHI = 150.03   PHIDOT = 243.98   G =-.0202   GDOT = 54.21   PSID =  69.08   PSIDOT = 359.51   PHITOT = 5.03
            F34 = 3.2649   F23 =10.1112   F12 =31.4382   PN = 1.0439    PNPSI = 1.0439  DPHI2 = .2347E+06
T = .00073  PHI = 150.10   PHIDOT = 245.18   G =-.0199   GDOT = 54.49   PSID =  69.18   PSIDOT = 362.13   PHITOT = 5.10
            F34 = 3.2654   F23 =10.1123   F12 =31.4409   PN = 1.0426    PNPSI = 1.0426  DPHI2 = .2318E+06
T = .00073  PHI = 150.17   PHIDOT = 246.30   G =-.0197   GDOT = 54.76   PSID =  69.29   PSIDOT = 364.65   PHITOT = 5.17
            F34 = 3.2531   F23 =10.1228   F12 =31.4590   PN = 1.0289    PNPSI = 1.0289  DPHI2 = .2094E+06
T = .00074  PHI = 150.24   PHIDOT = 247.37   G =-.0194   GDOT = 55.02   PSID =  69.39   PSIDOT = 367.10   PHITOT = 5.24
            F34 = 3.2536   F23 =10.1239   F12 =31.4616   PN = 1.0275    PNPSI = 1.0275  DPHI2 = .2066E+06
T = .00074  PHI = 150.31   PHIDOT = 248.37   G =-.0191   GDOT = 55.26   PSID =  69.50   PSIDOT = 369.45   PHITOT = 5.31
            F34 = 3.2411   F23 =10.1344   F12 =31.4796   PN = 1.0138    PNPSI = 1.0138  DPHI2 = .1844E+06
T = .00075  PHI = 150.38   PHIDOT = 249.31   G =-.0188   GDOT = 55.49   PSID =  69.60   PSIDOT = 371.74   PHITOT = 5.38
            F34 = 3.2416   F23 =10.1355   F12 =31.4821   PN = 1.0123    PNPSI = 1.0123  DPHI2 = .1818E+06
T = .00075  PHI = 150.45   PHIDOT = 250.18   G =-.0186   GDOT = 55.70   PSID =  69.71   PSIDOT = 373.92   PHITOT = 5.45
            F34 = 3.2290   F23 =10.1460   F12 =31.5001   PN =  .9986    PNPSI =  .9986  DPHI2 = .1599E+06
T = .00076  PHI = 150.52   PHIDOT = 251.01   G =-.0183   GDOT = 55.90   PSID =  69.82   PSIDOT = 376.04   PHITOT = 5.52
            F34 = 3.2295   F23 =10.1470   F12 =31.5026   PN =  .9972    PNPSI =  .9972  DPHI2 = .1574E+06
T = .00076  PHI = 150.59   PHIDOT = 251.78   G =-.0180   GDOT = 56.09   PSID =  69.93   PSIDOT = 378.06   PHITOT = 5.59
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                F34 = 3.5075   F23 =11.2700   F12 =31.5416   PN =  .9574   PNPSI =  .9574   DPHI2 =  .9488E+05
T =  .00077     PHI = 150.67   PHIDOT = 252.25   G =-.0177   GDOT = 56.22   PSID =  70.03   PSIDOT =  379.71   PHITOT =   5.67
                F34 = 3.5079   F23 =11.2711   F12 =31.5439   PN =  .9559   PNPSI =  .9559   DPHI2 =  .9277E+05
T =  .00077     PHI = 150.74   PHIDOT = 252.75   G =-.0174   GDOT = 56.35   PSID =  70.14   PSIDOT =  391.35   PHITOT =   5.74
                F34 = 3.5344   F23 =11.2899   F12 =31.5387   PN =  .9705   PNPSI =  .9705   DPHI2 =  .1158E+06
T =  .00078     PHI = 150.81   PHIDOT = 253.29   G =-.0172   GDOT = 56.48   PSID =  70.25   PSIDOT =  383.06   PHITOT =   5.81
                F34 = 3.5349   F23 =11.2910   F12 =31.5410   PN =  .9690   PNPSI =  .9690   DPHI2 =  .1136E+06
T =  .00078     PHI = 150.88   PHIDOT = 253.89   G =-.0169   GDOT = 56.64   PSID =  70.36   PSIDOT =  384.88   PHITOT =   5.88
                F34 = 3.5617   F23 =11.3099   F12 =31.5357   PN =  .9839   PNPSI =  .9839   DPHI2 =  .1368E+06
T =  .00079     PHI = 150.96   PHIDOT = 254.53   G =-.0166   GDOT = 56.80   PSID =  70.47   PSIDOT =  386.75   PHITOT =   5.96
                F34 = 3.5622   F23 =11.3110   F12 =31.5381   PN =  .9824   PNPSI =  .9824   DPHI2 =  .1345E+06
T =  .00079     PHI = 151.03   PHIDOT = 255.23   G =-.0163   GDOT = 56.97   PSID =  70.58   PSIDOT =  388.74   PHITOT =   6.03
                F34 = 3.5894   F23 =11.3301   F12 =31.5328   PN =  .9974   PNPSI =  .9974   DPHI2 =  .1578E+06
T =  .00080     PHI = 151.10   PHIDOT = 255.98   G =-.0160   GDOT = 57.15   PSID =  70.70   PSIDOT =  390.79   PHITOT =   6.10
                F34 = 3.5899   F23 =11.3312   F12 =31.5353   PN =  .9960   PNPSI =  .9960   DPHI2 =  .1554E+06
T =  .00080     PHI = 151.18   PHIDOT = 256.79   G =-.0157   GDOT = 57.35   PSID =  70.81   PSIDOT =  392.95   PHITOT =   6.18
                F34 = 3.6174   F23 =11.3504   F12 =31.5299   PN = 1.0113   PNPSI = 1.0113   DPHI2 =  .1738E+06
T =  .00081     PHI = 151.25   PHIDOT = 257.63   G =-.0155   GDOT = 57.56   PSID =  70.92   PSIDOT =  395.17   PHITOT =   6.25
                F34 = 3.6179   F23 =11.3515   F12 =31.5324   PN = 1.0098   PNPSI = 1.0098   DPHI2 =  .1763E+06
T =  .00081     PHI = 151.32   PHIDOT = 258.55   G =-.0152   GDOT = 57.78   PSID =  71.03   PSIDOT =  397.50   PHITOT =   6.32
                F34 = 3.6458   F23 =11.3709   F12 =31.5269   PN = 1.0253   PNPSI = 1.0253   DPHI2 =  .2000E+06
T =  .00082     PHI = 151.40   PHIDOT = 259.50   G =-.0149   GDOT = 58.01   PSID =  71.15   PSIDOT =  399.91   PHITOT =   6.40
                F34 = 3.6464   F23 =11.3721   F12 =31.5296   PN = 1.0238   PNPSI = 1.0238   DPHI2 =  .1974E+06
T =  .00082     PHI = 151.47   PHIDOT = 260.52   G =-.0146   GDOT = 58.26   PSID =  71.26   PSIDOT =  402.42   PHITOT =   6.47
                F34 = 3.6747   F23 =11.3916   F12 =31.5240   PN = 1.0397   PNPSI = 1.0397   DPHI2 =  .2212E+06
T =  .00083     PHI = 151.55   PHIDOT = 261.58   G =-.0143   GDOT = 58.51   PSID =  71.38   PSIDOT =  405.00   PHITOT =   6.55
                F34 = 3.6753   F23 =11.3928   F12 =31.5267   PN = 1.0382   PNPSI = 1.0382   DPHI2 =  .2185E+06
T =  .00083     PHI = 151.62   PHIDOT = 262.71   G =-.0140   GDOT = 58.78   PSID =  71.50   PSIDOT =  407.70   PHITOT =   6.62
                F34 = 3.3322   F23 =11.4156   F12 =31.5271   PN = 1.0468   PNPSI = 1.0468   DPHI2 =  .2311E+06
T =  .00084     PHI = 151.70   PHIDOT = 263.86   G =-.0137   GDOT = 59.05   PSID =  71.61   PSIDOT =  410.46   PHITOT =   6.70
                F34 = 3.3328   F23 =11.4169   F12 =31.5298   PN = 1.0453   PNPSI = 1.0453   DPHI2 =  .2283E+06
T =  .00084     PHI = 151.77   PHIDOT = 264.98   G =-.0134   GDOT = 59.32   PSID =  71.73   PSIDOT =  413.17   PHITOT =   6.77
                F34 = 3.3457   F23 =11.4463   F12 =31.5421   PN = 1.0389   PNPSI = 1.0389   DPHI2 =  .2180E+06
T =  .00085     PHI = 151.85   PHIDOT = 266.08   G =-.0131   GDOT = 59.58   PSID =  71.85   PSIDOT =  415.66   PHITOT =   6.85
                F34 = 3.3463   F23 =11.4475   F12 =31.5448   PN = 1.0373   PNPSI = 1.0373   DPHI2 =  .2152E+06
T =  .00085     PHI = 151.93   PHIDOT = 267.14   G =-.0128   GDOT = 59.83   PSID =  71.97   PSIDOT =  418.49   PHITOT =   6.93
                F34 = 3.3594   F23 =11.4772   F12 =31.5572   PN = 1.0308   PNPSI = 1.0308   DPHI2 =  .2049E+06
T =  .00086     PHI = 152.00   PHIDOT = 268.17   G =-.0125   GDOT = 60.08   PSID =  72.09   PSIDOT =  421.09   PHITOT =   7.00
                F34 = 3.3599   F23 =11.4784   F12 =31.5599   PN = 1.0292   PNPSI = 1.0292   DPHI2 =  .2022E+06
T =  .00086     PHI = 152.08   PHIDOT = 269.16   G =-.0122   GDOT = 60.32   PSID =  72.21   PSIDOT =  423.65   PHITOT =   7.08
                F34 = 3.3731   F23 =11.5084   F12 =31.5723   PN = 1.0226   PNPSI = 1.0226   DPHI2 =  .1919E+06
T =  .00087     PHI = 152.16   PHIDOT = 270.12   G =-.0119   GDOT = 60.55   PSID =  72.33   PSIDOT =  426.17   PHITOT =   7.16
                F34 = 3.3736   F23 =11.5096   F12 =31.5750   PN = 1.0210   PNPSI = 1.0210   DPHI2 =  .1893E+06
T =  .00087     PHI = 152.23   PHIDOT = 271.05   G =-.0116   GDOT = 60.77   PSID =  72.45   PSIDOT =  428.64   PHITOT =   7.23
                F34 = 3.3869   F23 =11.5398   F12 =31.5875   PN = 1.0143   PNPSI = 1.0143   DPHI2 =  .1789E+06
T =  .00088     PHI = 152.31   PHIDOT = 271.95   G =-.0113   GDOT = 60.99   PSID =  72.58   PSIDOT =  431.07   PHITOT =   7.31
                F34 = 3.3874   F23 =11.5410   F12 =31.5901   PN = 1.0127   PNPSI = 1.0127   DPHI2 =  .1764E+06
T =  .00088     PHI = 152.39   PHIDOT = 272.81   G =-.0110   GDOT = 61.20   PSID =  72.70   PSIDOT =  433.46   PHITOT =   7.39
                F34 = 3.4008   F23 =11.5715   F12 =31.6027   PN = 1.0058   PNPSI = 1.0058   DPHI2 =  .1660E+06
T =  .00089     PHI = 152.47   PHIDOT = 273.65   G =-.0107   GDOT = 61.40   PSID =  72.83   PSIDOT =  435.81   PHITOT =   7.47
                F34 = 3.4013   F23 =11.5727   F12 =31.6053   PN = 1.0043   PNPSI = 1.0043   DPHI2 =  .1636E+06
T =  .00089     PHI = 152.55   PHIDOT = 274.43   G =-.0104   GDOT = 61.59   PSID =  72.95   PSIDOT =  438.07   PHITOT =   7.55
                F34 = 3.7883   F23 =11.6051   F12 =31.6211   PN =  .9933   PNPSI =  .9933   DPHI2 =  .1472E+06
T =  .00090     PHI = 152.63   PHIDOT = 275.12   G =-.0101   GDOT = 61.76   PSID =  73.08   PSIDOT =  440.20   PHITOT =   7.63
                F34 = 3.7888   F23 =11.6062   F12 =31.6236   PN =  .9917   PNPSI =  .9917   DPHI2 =  .1450E+06
T =  .00090     PHI = 152.70   PHIDOT = 275.88   G =-.0098   GDOT = 61.94   PSID =  73.20   PSIDOT =  442.45   PHITOT =   7.70
                F34 = 3.8195   F23 =11.6275   F12 =31.6182   PN = 1.0083   PNPSI = 1.0083   DPHI2 =  .1698E+06
T =  .00091     PHI = 152.78   PHIDOT = 276.68   G =-.0095   GDOT = 62.13   PSID =  73.33   PSIDOT =  444.77   PHITOT =   7.78
                F34 = 3.8201   F23 =11.6286   F12 =31.6206   PN = 1.0067   PNPSI = 1.0067   DPHI2 =  .1675E+06
T =  .00091     PHI = 152.86   PHIDOT = 277.55   G =-.0091   GDOT = 62.34   PSID =  73.46   PSIDOT =  447.22   PHITOT =   7.86
                F34 = 3.8512   F23 =11.6500   F12 =31.6149   PN = 1.0236   PNPSI = 1.0236   DPHI2 =  .1925E+06
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T =  .00092   PHI = 152.94   PHIDOT = 278.47    G =-.0088   GDOT = 62.56   PSID =  73.59   PSIDOT =  449.74   PHITOT =   7.94
              F34 = 3.8518   F23 =11.6512   F12 =31.6175    PN = 1.0220    PNPSI = 1.0220  DPHI2 =   .1900E+06
T =  .00092   PHI = 153.02   PHIDOT = 279.45    G =-.0085   GDOT = 62.79   PSID =  73.72   PSIDOT =  452.38   PHITOT =   8.02
              F34 = 3.8834   F23 =11.6727   F12 =31.6117    PN = 1.0392    PNPSI = 1.0392  DPHI2 =   .2153E+06
T =  .00093   PHI = 153.10   PHIDOT = 280.48    G =-.0082   GDOT = 63.04   PSID =  73.85   PSIDOT =  455.10   PHITOT =   8.10
              F34 = 3.8840   F23 =11.6740   F12 =31.6145    PN = 1.0376    PNPSI = 1.0376  DPHI2 =   .2127E+06
T =  .00093   PHI = 153.18   PHIDOT = 281.58    G =-.0079   GDOT = 63.30   PSID =  73.98   PSIDOT =  457.95   PHITOT =   8.18
              F34 = 3.9161   F23 =11.6957   F12 =31.6086    PN = 1.0551    PNPSI = 1.0551  DPHI2 =   .2383E+06
T =  .00094   PHI = 153.26   PHIDOT = 282.72    G =-.0076   GDOT = 63.56   PSID =  74.11   PSIDOT =  460.88   PHITOT =   8.26
              F34 = 3.9167   F23 =11.6970   F12 =31.6114    PN = 1.0535    PNPSI = 1.0535  DPHI2 =   .23[illegible]5E+06
T =  .00094   PHI = 153.35   PHIDOT = 283.94    G =-.0073   GDOT = 63.85   PSID =  74.24   PSIDOT =  463.94   PHITOT =   8.35
              F34 = 3.9493   F23 =11.7189   F12 =31.6055    PN = 1.0713    PNPSI = 1.0713  DPHI2 =   .2613E+06
T =  .00095   PHI = 153.43   PHIDOT = 285.19    G =-.0069   GDOT = 64.14   PSID =  74.37   PSIDOT =  467.08   PHITOT =   8.43
              F34 = 3.9500   F23 =11.7202   F12 =31.6083    PN = 1.0697    PNPSI = 1.0697  DPHI2 =   .258[illegible]E+06
T =  .00095   PHI = 153.51   PHIDOT = 286.52    G =-.0066   GDOT = 64.45   PSID =  74.51   PSIDOT =  470.[illegible]   PHITOT =   8.51
              F34 = 3.5849   F23 =11.7445   F12 =31.6062    PN = 1.0828    PNPSI = 1.0828  DPHI2 =   .2771E+06
T =  .00096   PHI = 153.59   PHIDOT = 287.89    G =-.0063   GDOT = 64.77   PSID =  74.64   PSIDOT =  473.70   PHITOT =   8.59
              F34 = 3.5855   F23 =11.7458   F12 =31.6091    PN = 1.0811    PNPSI = 1.0811  DPHI2 =   .2741E+06
T =  .00096   PHI = 153.67   PHIDOT = 289.24    G =-.0060   GDOT = 65.08   PSID =  74.78   PSIDOT =  477.04   PHITOT =   8.67
              F34 = 3.5853   F23 =10.5805   F12 =31.6261    PN = 1.0692    PNPSI = 1.0692  DPHI2 =   .2561E+06
T =  .00097   PHI = 153.76   PHIDOT = 290.54    G =-.0056   GDOT = 65.39   PSID =  74.92   PSIDOT =  480.31   PHITOT =   8.76
              F34 = 3.5950   F23 =10.5817   F12 =31.6290    PN = 1.0675    PNPSI = 1.0675  DPHI2 =   .2532E+06
T =  .00097   PHI = 153.84   PHIDOT = 291.77    G =-.0053   GDOT = 65.67   PSID =  75.05   PSIDOT =  483.47   PHITOT =   8.84
              F34 = 3.5697   F23 =10.5937   F12 =31.6496    PN = 1.0508    PNPSI = 1.0508  DPHI2 =   .2285E+06
T =  .00098   PHI = 153.92   PHIDOT = 292.94    G =-.0050   GDOT = 65.94   PSID =  75.19   PSIDOT =  486.54   PHITOT =   8.92
              F34 = 3.5703   F23 =10.5949   F12 =31.6524    PN = 1.0491    PNPSI = 1.0491  DPHI2 =   .2257E+06
T =  .00098   PHI = 154.01   PHIDOT = 294.03    G =-.0047   GDOT = 66.20   PSID =  75.33   PSIDOT =  489.49   PHITOT =   9.01
              F34 = 3.5539   F23 =10.6070   F12 =31.6730    PN = 1.0324    PNPSI = 1.0324  DPHI2 =   .2012E+06
T =  .00099   PHI = 154.09   PHIDOT = 295.06    G =-.0043   GDOT = 66.44   PSID =  75.47   PSIDOT =  492.36   PHITOT =   9.09
              F34 = 3.5545   F23 =10.6081   F12 =31.6757    PN = 1.0307    PNPSI = 1.0307  DPHI2 =   .1987E+06
T =  .00099   PHI = 154.18   PHIDOT = 296.01    G =-.0040   GDOT = 66.66   PSID =  75.62   PSIDOT =  495.10   PHITOT =   9.18
              F34 = 3.5380   F23 =10.6201   F12 =31.6961    PN = 1.0139    PNPSI = 1.0139  DPHI2 =   .1745E+06
T =  .00100   PHI = 154.26   PHIDOT = 296.91    G =-.0037   GDOT = 66.87   PSID =  75.76   PSIDOT =  497.77   PHITOT =   9.26
              F34 = 3.5396   F23 =10.6212   F12 =31.6938    PN = 1.0122    PNPSI = 1.0122  DPHI2 =   .1721E+06
T =  .00100   PHI = 154.35   PHIDOT = 297.74    G =-.0033   GDOT = 67.06   PSID =  75.90   PSIDOT =  500.31   PHITOT =   9.35
              F34 = 3.5220   F23 =10.6332   F12 =31.7191    PN =  .9956    PNPSI =  .9956  DPHI2 =   .1483E+06
T =  .00101   PHI = 154.43   PHIDOT = 298.50    G =-.0030   GDOT = 67.24   PSID =  76.04   PSIDOT =  502.77   PHITOT =   9.43
              F34 = 3.5225   F23 =10.6342   F12 =31.7217    PN =  .9938    PNPSI =  .9938  DPHI2 =   .1461E+06
T =  .00101   PHI = 154.52   PHIDOT = 299.14    G =-.0026   GDOT = 67.39   PSID =  76.19   PSIDOT =  505.01   PHITOT =   9.52
              F34 = 3.6962   F23 =10.6439   F12 =31.7373    PN =  .9834    PNPSI =  .9834  DPHI2 =   .13[illegible]5E+06
T =  .00102   PHI = 154.60   PHIDOT = 299.77    G =-.0023   GDOT = 67.54   PSID =  76.33   PSIDOT =  507.24   PHITOT =   9.60
              F34 = 3.8968   F23 =10.6449   F12 =31.7399    PN =  .9816    PNPSI =  .9816  DPHI2 =   .1294E+06
T =  .00102   PHI = 154.69   PHIDOT = 300.43    G =-.0020   GDOT = 67.69   PSID =  76.48   PSIDOT =  509.54   PHITOT =   9.69
              F34 = 3.8960   F23 =10.6476   F12 =31.7409    PN =  .9906    PNPSI =  .9906  DPHI2 =   .1427E+06
T =  .00103   PHI = 154.78   PHIDOT = 301.12    G =-.0016   GDOT = 67.85   PSID =  76.63   PSIDOT =  511.88   PHITOT =   9.78
              F34 = 3.8965   F23 =10.6487   F12 =31.7435    PN =  .9889    PNPSI =  .9889  DPHI2 =   .1406E+06
T =  .00103   PHI = 154.86   PHIDOT = 301.84    G =-.0013   GDOT = 68.02   PSID =  76.77   PSIDOT =  514.29   PHITOT =   9.86
              F34 = 3.8958   F23 =10.6514   F12 =31.7447    PN =  .9979    PNPSI =  .9979  DPHI2 =   .1538E+06
T =  .00104   PHI = 154.95   PHIDOT = 302.58    G =-.0010   GDOT = 68.19   PSID =  76.92   PSIDOT =  516.74   PHITOT =   9.95
              F34 = 3.8963   F23 =10.6524   F12 =31.7473    PN =  .9961    PNPSI =  .9961  DPHI2 =   .151[illegible]E+06
T =  .00104   PHI = 155.04   PHIDOT = 303.35    G =-.0006   GDOT = 68.37   PSID =  77.07   PSIDOT =  519.26   PHITOT =  10.04
              F34 = 3.8956   F23 =10.6552   F12 =31.7485    PN = 1.0051    PNPSI = 1.0051  DPHI2 =   .1648E+06
T =  .00105   PHI = 155.12   PHIDOT = 304.15    G =-.0003   GDOT = 68.55   PSID =  77.22   PSIDOT =  521.81   PHITOT =  10.12
              F34 = 3.8961   F23 =10.6563   F12 =31.7511    PN = 1.0034    PNPSI = 1.0034  DPHI2 =   .1625E+06
T =  .00105   PHI = 155.21   PHIDOT = 304.98    G = .0001   GDOT = 68.74   PSID =  77.37   PSIDOT =  524.44   PHITOT =  10.21
              F34 = 3.8954   F23 =10.6591   F12 =31.7525    PN = 1.0124    PNPSI = 1.0124  DPHI2 =   .1756E+08

FREE MOTION

T =  .00105   PHI = 185.21   PHIDOT = 304.98   PSI = 285.22   PSIDOT =  524.44   PHITOT =  10.21
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                  FF12 = 29.530   FF23 =  9.586   FF34 =  3.196
T =   .00106      PHI = 185.40    PHIDOT = 349.71   PSI = 285.52   PSIDOT =  505.14   PHITOT =  10.40
                  FF12 = 29.566   FF23 =  9.608   FF34 =  2.863
T =   .00107      PHI = 185.61    PHIDOT = 394.21   PSI = 285.80   PSIDOT =  485.85   PHITOT =  10.61
                  FF12 = 29.568   FF23 =  9.609   FF34 =  2.864
T =   .00108      PHI = 185.67    PHIDOT = 404.69   PSI = 285.87   PSIDOT =  481.03   PHITOT =  10.67
                  FF12   26.595   FF23 =  9.644   FF34 =  2.821
T =   .00108      PHI = 185.73    PHIDOT = 415.02   PSI = 285.94   PSIDOT =  476.20   PHITOT =  10.73
                  FF12 = 26.595   FF23 =  9.644   FF34 =  2.821
T =   .00108      PHI = 185.79    PHIDOT = 424.92   PSI = 286.01   PSIDOT =  471.38   PHITOT =  10.79
                  FF12 = 26.662   FF23 = 10.720   FF34 =  3.082
T =   .00108      PHI = 185.85    PHIDOT = 434.79   PSI = 286.08   PSIDOT =  466.56   PHITOT =  10.85
                  FF12 = 26.662   FF23 = 10.720   FF34 =  3.082
T =   .00109      PHI = 185.91    PHIDOT = 444.75   PSI = 286.14   PSIDOT =  461.73   PHITOT =  10.91
                  FF12 = 26.633   FF23 = 10.702   FF34 =  3.089
T =   .00109      PHI = 185.98    PHIDOT = 454.76   PSI = 286.21   PSIDOT =  456.91   PHITOT =  10.98
                  FF12 = 26.633   FF23 = 10.702   FF34 =  3.090
T =   .00109      PHI = 186.04    PHIDOT = 464.88   PSI = 286.27   PSIDOT =  452.09   PHITOT =  11.04
                  FF12 = 26.602   FF23 = 10.683   FF34 =  3.097
T =   .00109      PHI = 186.11    PHIDOT = 475.02   PSI = 286.34   PSIDOT =  447.26   PHITOT =  11.11
                  FF12 = 26.603   FF23 = 10.684   FF34 =  3.097
T =   .00110      PHI = 186.18    PHIDOT = 485.27   PSI = 286.40   PSIDOT =  442.44   PHITOT =  11.18
                  FF12 = 26.570   FF23 = 10.664   FF34 =  3.106
T =   .00110      PHI = 186.25    PHIDOT = 495.59   PSI = 286.46   PSIDOT =  437.61   PHITOT =  11.25
                  FF12 = 26.571   FF23 = 10.664   FF34 =  3.106
T =   .00110      PHI = 186.32    PHIDOT = 506.00   PSI = 286.53   PSIDOT =  432.79   PHITOT =  11.32
                  FF12 = 26.537   FF23 = 10.643   FF34 =  3.114
T =   .00110      PHI = 186.39    PHIDOT = 516.47   PSI = 286.59   PSIDOT =  427.97   PHITOT =  11.39
                  FF12 = 26.537   FF23 = 10.644   FF34 =  3.114
T =   .00111      PHI = 186.47    PHIDOT = 527.05   PSI = 286.65   PSIDOT =  423.14   PHITOT =  11.47
                  FF12 = 26.502   FF23 = 10.622   FF34 =  3.123
T =   .00111      PHI = 186.54    PHIDOT = 537.70   PSI = 286.71   PSIDOT =  418.32   PHITOT =  11.54
                  FF12 = 26.502   FF23 = 10.622   FF34 =  3.123
T =   .00111      PHI = 186.62    PHIDOT = 548.45   PSI = 286.77   PSIDOT =  413.50   PHITOT =  11.62
                  FF12 = 26.465   FF23 = 10.600   FF34 =  3.132
T =   .00111      PHI = 186.70    PHIDOT = 559.28   PSI = 286.83   PSIDOT =  408.67   PHITOT =  11.70
                  FF12 = 26.466   FF23 = 10.600   FF34 =  3.132
T =   .00112      PHI = 186.78    PHIDOT = 570.21   PSI = 286.89   PSIDOT =  403.85   PHITOT =  11.78
                  FF12 = 26.450   FF23 = 10.590   FF34 =  2.830
T =   .00112      PHI = 186.86    PHIDOT = 581.19   PSI = 286.94   PSIDOT =  399.03   PHITOT =  11.86
                  FF12 = 26.450   FF23 = 10.590   FF34 =  2.830
T =   .00112      PHI = 186.95    PHIDOT = 592.11   PSI = 287.00   PSIDOT =  394.20   PHITOT =  11.95
                  FF12 = 26.463   FF23 = 10.598   FF34 =  2.838
T =   .00112      PHI = 187.03    PHIDOT = 602.99   PSI = 287.06   PSIDOT =  389.38   PHITOT =  12.03
                  FF12 = 26.464   FF23 = 10.598   FF34 =  2.839
T =   .00113      PHI = 187.12    PHIDOT = 613.82   PSI = 287.11   PSIDOT =  384.56   PHITOT =  12.12
                  FF12 = 26.478   FF23 = 10.606   FF34 =  2.847
T =   .00113      PHI = 187.21    PHIDOT = 624.61   PSI = 287.17   PSIDOT =  379.73   PHITOT =  12.21
                  FF12 = 26.479   FF23 = 10.606   FF34 =  2.847
T =   .00113      PHI = 187.30    PHIDOT = 635.33   PSI = 287.22   PSIDOT =  374.91   PHITOT =  12.30
                  FF12 = 26.493   FF23 = 10.615   FF34 =  2.856
T =   .00113      PHI = 187.39    PHIDOT = 646.03   PSI = 287.27   PSIDOT =  370.09   PHITOT =  12.39
                  FF12 = 26.494   FF23 = 10.615   FF34 =  2.857
T =   .00114      PHI = 187.49    PHIDOT = 656.65   PSI = 287.33   PSIDOT =  365.26   PHITOT =  12.49
                  FF12 = 26.510   FF23 = 10.624   FF34 =  2.866
T =   .00114      PHI = 187.58    PHIDOT = 667.24   PSI = 287.38   PSIDOT =  360.44   PHITOT =  12.58
                  FF12 = 26.510   FF23 = 10.624   FF34 =  2.866
T =   .00114      PHI = 187.68    PHIDOT = 677.76   PSI = 287.43   PSIDOT =  355.62   PHITOT =  12.68
                  FF12 = 26.538   FF23 = 10.640   FF34 =  3.192
T =   .00114      PHI = 187.77    PHIDOT = 688.12   PSI = 287.48   PSIDOT =  350.79   PHITOT =  12.77
                  FF12 = 26.539   FF23 = 10.640   FF34 =  3.192
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T = .00115  PHI = 187.87   PHIDOT = 698.58   PSI = 287.53   PSIDOT =  345.97   PHITOT =  12.87
            FF12 = 26.491   FF23 = 10.611   FF34 =   3.204
T = .00115  PHI = 187.97   PHIDOT = 709.12   PSI = 287.59   PSIDOT =  341.15   PHITOT =  12.97
            FF12 = 26.492   FF23 = 10.612   FF34 =   3.204
T = .00115  PHI = 188.08   PHIDOT = 719.81   PSI = 287.63   PSIDOT =  336.32   PHITOT =  13.08
            FF12 = 26.443   FF23 = 10.582   FF34 =   3.216
T = .00115  PHI = 188.18   PHIDOT = 730.60   PSI = 287.68   PSIDOT =  331.50   PHITOT =  13.18
            FF12 = 26.444   FF23 = 10.582   FF34 =   3.216
T = .00116  PHI = 188.29   PHIDOT = 741.53   PSI = 287.72   PSIDOT =  326.68   PHITOT =  13.29
            FF12 = 26.394   FF23 = 10.551   FF34 =   3.228
T = .00116  PHI = 188.39   PHIDOT = 752.55   PSI = 287.77   PSIDOT =  321.85   PHITOT =  13.39
            FF12 = 26.395   FF23 = 10.552   FF34 =   3.228
T = .00116  PHI = 188.50   PHIDOT = 763.73   PSI = 287.82   PSIDOT =  317.03   PHITOT =  13.50
            FF12 = 26.343   FF23 = 10.520   FF34 =   3.241
T = .00116  PHI = 188.61   PHIDOT = 775.01   PSI = 287.86   PSIDOT =  312.21   PHITOT =  13.61
            FF12 = 26.344   FF23 = 10.521   FF34 =   3.241
T = .00117  PHI = 188.72   PHIDOT = 786.45   PSI = 287.90   PSIDOT =  307.38   PHITOT =  13.72
            FF12 = 26.328   FF23 =  9.447   FF34 =   2.929
T = .00117  PHI = 188.84   PHIDOT = 797.91   PSI = 287.95   PSIDOT =  302.56   PHITOT =  13.84
            FF12 = 26.329   FF23 =  9.448   FF34 =   2.929
T = .00117  PHI = 188.95   PHIDOT = 809.24   PSI = 287.99   PSIDOT =  297.74   PHITOT =  13.95
            FF12 = 26.378   FF23 =  9.447   FF34 =   2.909
T = .00117  PHI = 189.07   PHIDOT = 820.46   PSI = 288.03   PSIDOT =  292.91   PHITOT =  14.07
            FF12 = 26.379   FF23 =  9.448   FF34 =   2.909
T = .00118  PHI = 189.19   PHIDOT = 831.49   PSI = 288.08   PSIDOT =  288.09   PHITOT =  14.19
            FF12 = 26.428   FF23 =  9.447   FF34 =   2.889
T = .00118  PHI = 189.31   PHIDOT = 842.42   PSI = 288.12   PSIDOT =  283.27   PHITOT =  14.31
            FF12 = 26.430   FF23 =  9.447   FF34 =   2.889
T = .00118  PHI = 189.43   PHIDOT = 853.16   PSI = 283.16   PSIDOT =  278.44   PHITOT =  14.43
            FF12 = 26.480   FF23 =  9.446   FF34 =   2.868
T = .00118  PHI = 189.55   PHIDOT = 863.78   PSI = 288.20   PSIDOT =  273.62   PHITOT =  14.55
            FF12 = 26.481   FF23 =  9.446   FF34 =   2.869
T = .00119  PHI = 189.68   PHIDOT = 874.09   PSI = 288.23   PSIDOT =  268.79   PHITOT =  14.68
            FF12 = 26.511   FF23 =  9.434   FF34 =   3.161
T = .00119  PHI = 189.80   PHIDOT = 884.40   PSI = 288.27   PSIDOT =  263.97   PHITOT =  14.80
            FF12 = 26.513   FF23 =  9.434   FF34 =   3.161
T = .00119  PHI = 189.93   PHIDOT = 894.78   PSI = 288.31   PSIDOT =  259.15   PHITOT =  14.93
            FF12 = 26.484   FF23 =  9.389   FF34 =   3.138
T = .00119  PHI = 190.06   PHIDOT = 905.20   PSI = 288.35   PSIDOT =  254.32   PHITOT =  15.06
            FF12 = 26.486   FF23 =  9.390   FF34 =   3.138
T = .00120  PHI = 190.19   PHIDOT = 915.71   PSI = 288.38   PSIDOT =  249.50   PHITOT =  15.19
            FF12 = 26.457   FF23 =  9.345   FF34 =   3.114
T = .00120  PHI = 190.32   PHIDOT = 926.26   PSI = 288.42   PSIDOT =  244.68   PHITOT =  15.32
            FF12 = 26.458   FF23 =  9.345   FF34 =   3.114
T = .00120  PHI = 190.45   PHIDOT = 936.89   PSI = 288.45   PSIDOT =  239.85   PHITOT =  15.45
            FF12 = 26.429   FF23 =  9.299   FF34 =   3.090
T = .00120  PHI = 190.59   PHIDOT = 947.56   PSI = 283.49   PSIDOT =  235.03   PHITOT =  15.59
            FF12 = 26.431   FF23 =  9.300   FF34 =   3.090
T = .00121  PHI = 190.73   PHIDOT = 958.26   PSI = 288.52   PSIDOT =  230.21   PHITOT =  15.73
            FF12 = 26.468   FF23 =  9.288   FF34 =   2.761
T = .00121  PHI = 190.86   PHIDOT = 968.84   PSI = 288.55   PSIDOT =  225.38   PHITOT =  15.86
            FF12 = 26.470   FF23 =  9.289   FF34 =   2.761
T = .00121  PHI = 191.00   PHIDOT = 979.22   PSI = 288.59   PSIDOT =  220.56   PHITOT =  16.00
            FF12 = 26.526   FF23 =  9.286   FF34 =   2.737
T = .00121  PHI = 191.14   PHIDOT = 989.47   PSI = 283.62   PSIDOT =  215.74   PHITOT =  16.14
            FF12 = 26.527   FF23 =  9.287   FF34 =   2.737
T = .00122  PHI = 191.29   PHIDOT = 999.52   PSI = 288.65   PSIDOT =  210.91   PHITOT =  16.29
            FF12 = 26.583   FF23 =  9.284   FF34 =   2.713
T = .00122  PHI = 191.43   PHIDOT =1009.43   PSI = 283.68   PSIDOT =  206.09   PHITOT =  16.43
            FF12 = 26.585   FF23 =  9.285   FF34 =   2.714
T = .00122  PHI = 191.50   PHIDOT =1014.19   PSI = 288.69   PSIDOT =  203.68   PHITOT =  16.50
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Computer program SANDA3 (cont)

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                FF12 = 26.622    FF23 = 10.296    FF34 =   2.969
T =  .00122     PHI = 191.58    PHIDOT =1018.95    PSI = 288.71    PSIDOT =  201.27   PHITOT =  16.58
                FF12 = 26.623    FF23 = 10.297    FF34 =   2.969
T =  .00122     PHI = 191.65    PHIDOT =1023.75    PSI = 288.72    PSIDOT =  198.86   PHITOT =  15.65
                FF12 = 26.590    FF23 = 10.277    FF34 =   2.977
T =  .00122     PHI = 191.72    PHIDOT =1028.59    PSI = 288.73    PSIDOT =  196.44   PHITOT =  16.72
                FF12 = 26.591    FF23 = 10.277    FF34 =   2.978
T =  .00123     PHI = 191.80    PHIDOT =1033.48    PSI = 288.75    PSIDOT =  194.03   PHITOT =  16.80
                FF12 = 26.558    FF23 = 10.257    FF34 =   2.986
T =  .00123     PHI = 191.87    PHIDOT =1038.39    PSI = 288.76    PSIDOT =  191.62   PHITOT =  16.87
                FF12 = 26.559    FF23 = 10.257    FF34 =   2.986
T =  .00123     PHI = 191.95    PHIDOT =1043.36    PSI = 288.78    PSIDOT =  189.21   PHITOT =  16.95
                FF12 = 26.525    FF23 = 10.237    FF34 =   2.995
T =  .00123     PHI = 192.02    PHIDOT =1048.36    PSI = 288.79    PSIDOT =  186.80   PHITOT =  17.02
                FF12 = 26.526    FF23 = 10.237    FF34 =   2.995
T =  .00123     PHI = 192.10    PHIDOT =1053.41    PSI = 288.80    PSIDOT =  184.38   PHITOT =  17.10
                FF12 = 26.492    FF23 = 10.217    FF34 =   3.003
T =  .00123     PHI = 192.17    PHIDOT =1058.49    PSI = 288.82    PSIDOT =  181.97   PHITOT =  17.17
                FF12 = 26.493    FF23 = 10.217    FF34 =   3.003
T =  .00123     PHI = 192.25    PHIDOT =1063.62    PSI = 288.83    PSIDOT =  179.56   PHITOT =  17.25
                FF12 = 26.458    FF23 = 10.196    FF34 =   3.012
T =  .00123     PHI = 192.32    PHIDOT =1068.79    PSI = 288.84    PSIDOT =  177.15   PHITOT =  17.32
                FF12 = 26.459    FF23 = 10.197    FF34 =   3.012
T =  .00124     PHI = 192.40    PHIDOT =1073.99    PSI = 288.85    PSIDOT =  174.74   PHITOT =  17.40
                FF12 = 26.463    FF23 = 10.198    FF34 =   2.721
T =  .00124     PHI = 192.48    PHIDOT =1079.17    PSI = 288.87    PSIDOT =  172.33   PHITOT =  17.48
                FF12 = 26.464    FF23 = 10.198    FF34 =   2.721
T =  .00124     PHI = 192.55    PHIDOT =1084.33    PSI = 288.88    PSIDOT =  169.91   PHITOT =  17.55
                FF12 = 26.475    FF23 = 10.204    FF34 =   2.728
T =  .00124     PHI = 192.63    PHIDOT =1089.48    PSI = 288.89    PSIDOT =  167.50   PHITOT =  17.63
                FF12 = 26.476    FF23 = 10.205    FF34 =   2.728
T =  .00124     PHI = 192.71    PHIDOT =1094.60    PSI = 288.90    PSIDOT =  165.09   PHITOT =  17.71
                FF12 = 26.488    FF23 = 10.211    FF34 =   2.735
T =  .00124     PHI = 192.79    PHIDOT =1099.70    PSI = 288.91    PSIDOT =  162.68   PHITOT =  17.79
                FF12 = 26.489    FF23 = 10.211    FF34 =   2.736
T =  .00124     PHI = 192.87    PHIDOT =1104.78    PSI = 288.93    PSIDOT =  160.27   PHITOT =  17.87
                FF12 = 26.502    FF23 = 10.218    FF34 =   2.743
T =  .00124     PHI = 192.95    PHIDOT =1109.84    PSI = 283.94    PSIDOT =  157.86   PHITOT =  17.95
                FF12 = 26.502    FF23 = 10.218    FF34 =   2.743
T =  .00125     PHI = 193.03    PHIDOT =1114.88    PSI = 288.95    PSIDOT =  155.44   PHITOT =  18.03
                FF12 = 26.515    FF23 = 10.224    FF34 =   2.751
T =  .00125     PHI = 193.11    PHIDOT =1119.89    PSI = 288.96    PSIDOT =  153.03   PHITOT =  18.11
                FF12 = 26.516    FF23 = 10.225    FF34 =   2.751
T =  .00125     PHI = 193.19    PHIDOT =1124.89    PSI = 288.97    PSIDOT =  150.62   PHITOT =  18.19
                FF12 = 26.556    FF23 = 10.248    FF34 =   3.062
T =  .00125     PHI = 193.27    PHIDOT =1129.85    PSI = 288.98    PSIDOT =  148.21   PHITOT =  18.27
                FF12 = 26.557    FF23 = 10.248    FF34 =   3.062
T =  .00125     PHI = 193.35    PHIDOT =1134.76    PSI = 288.99    PSIDOT =  145.80   PHITOT =  18.35
                FF12 = 29.590    FF23 =  9.922    FF34 =   2.974
T =  .00125     PHI = 193.43    PHIDOT =1139.71    PSI = 289.00    PSIDOT =  143.39   PHITOT =  18.43
                FF12 = 29.592    FF23 =  9.922    FF34 =   2.974
T =  .00125     PHI = 193.51    PHIDOT =1144.51    PSI = 289.01    PSIDOT =  140.97   PHITOT =  18.51
                FF12 = 29.555    FF23 =  9.926    FF34 =   2.991
T =  .00125     PHI = 193.59    PHIDOT =1149.35    PSI = 289.02    PSIDOT =  138.56   PHITOT =  18.59
                FF12 = 29.556    FF23 =  9.926    FF34 =   2.991
T =  .00126     PHI = 193.68    PHIDOT =1154.25    PSI = 289.03    PSIDOT =  136.15   PHITOT =  18.68
                FF12 = 29.518    FF23 =  9.930    FF34 =   3.008
T =  .00126     PHI = 193.76    PHIDOT =1159.20    PSI = 289.04    PSIDOT =  133.74   PHITOT =  18.76
                FF12 = 29.519    FF23 =  9.930    FF34 =   3.009
T =  .00126     PHI = 193.84    PHIDOT =1164.21    PSI = 289.05    PSIDOT =  131.33   PHITOT =  18.84
                FF12 = 29.481    FF23 =  9.933    FF34 =   3.026
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    T =  .00126   PHI = 193.93    PHIDOT =1169.27   PSI = 289.06    PSIDOT =  128.92   PHITOT =  18.93
                  FF12 = 29.482    FF23 =  9.934   FF34 =  3.026
    T =  .00126   PHI = 194.01    PHIDOT =1174.39   PSI = 289.07    PSIDOT =  126.50   PHITOT =  19.01
                  FF12 = 29.443    FF23 =  9.937   FF34 =  3.044
    T =  .00126   PHI = 194.10    PHIDOT =1179.56   PSI = 289.08    PSIDOT =  124.09   PHITOT =  19.10
                  FF12 = 29.444    FF23 =  9.937   FF34 =  3.044
    T =  .00126   PHI = 194.18    PHIDOT =1184.79   PSI = 289.09    PSIDOT =  121.68   PHITOT =  19.18
                  FF12 = 29.405    FF23 =  9.940   FF34 =  3.061
    T =  .00126   PHI = 194.26    PHIDOT =1190.07   PSI = 289.10    PSIDOT =  119.27   PHITOT =  19.26
                  FF12 = 29.406    FF23 =  9.940   FF34 =  3.061
    T =  .00127   PHI = 194.35    PHIDOT =1195.38   PSI = 289.10    PSIDOT =  116.86   PHITOT =  19.35
                  FF12 = 29.432    FF23 =  8.963   FF34 =  2.765
    T =  .00127   PHI = 194.44    PHIDOT =1200.68   PSI = 289.11    PSIDOT =  114.44   PHITOT =  19.44
                  FF12 = 29.433    FF23 =  8.963   FF34 =  2.765
    T =  .00127   PHI = 194.52    PHIDOT =1205.92   PSI = 289.12    PSIDOT =  112.03   PHITOT =  19.52
                  FF12 = 29.474    FF23 =  8.985   FF34 =  2.759
    T =  .00127   PHI = 194.61    PHIDOT =1211.14   PSI = 289.13    PSIDOT =  109.62   PHITOT =  19.61
                  FF12 = 29.475    FF23 =  8.986   FF34 =  2.759
    T =  .00127   PHI = 194.70    PHIDOT =1216.30   PSI = 289.14    PSIDOT =  107.21   PHITOT =  19.70
                  FF12 = 29.517    FF23 =  9.008   FF34 =  2.752
    T =  .00127   PHI = 194.78    PHIDOT =1221.43   PSI = 289.14    PSIDOT =  104.80   PHITOT =  19.78
                  FF12 = 29.519    FF23 =  9.009   FF34 =  2.753
    T =  .00127   PHI = 194.87    PHIDOT =1226.51   PSI = 289.15    PSIDOT =  102.39   PHITOT =  19.87
                  FF12 = 29.561    FF23 =  9.031   FF34 =  2.746
    T =  .00127   PHI = 194.96    PHIDOT =1231.55   PSI = 289.16    PSIDOT =   99.97   PHITOT =  19.96
                  FF12 = 29.562    FF23 =  9.032   FF34 =  2.746
    T =  .00128   PHI = 195.05    PHIDOT =1236.55   PSI = 289.17    PSIDOT =   97.56   PHITOT =  20.05
                  FF12 = 29.605    FF23 =  9.054   FF34 =  2.739
    T =  .00128   PHI = 195.14    PHIDOT =1241.51   PSI = 289.17    PSIDOT =   95.15   PHITOT =  20.14
                  FF12 = 29.606    FF23 =  9.055   FF34 =  2.739
    T =  .00128   PHI = 195.23    PHIDOT =1246.37   PSI = 289.18    PSIDOT =   92.74   PHITOT =  20.23
                  FF12 = 29.636    FF23 =  9.072   FF34 =  3.034
    T =  .00128   PHI = 195.31    PHIDOT =1251.23   PSI = 289.19    PSIDOT =   90.33   PHITOT =  20.31
                  FF12 = 29.637    FF23 =  9.072   FF34 =  3.034
    T =  .00128   PHI = 195.49    PHIDOT =1261.07   PSI = 289.20    PSIDOT =   85.50   PHITOT =  20.49
                  FF12 = 29.602    FF23 =  9.061   FF34 =  3.020
    T =  .00128   PHI = 195.68    PHIDOT =1271.00   PSI = 289.21    PSIDOT =   80.68   PHITOT =  20.68
                  FF12 = 29.604    FF23 =  9.062   FF34 =  3.020
    T =  .00129   PHI = 195.86    PHIDOT =1281.08   PSI = 289.22    PSIDOT =   75.86   PHITOT =  20.88
                  FF12 = 29.569    FF23 =  9.052   FF34 =  3.006
    T =  .00129   PHI = 196.04    PHIDOT =1291.27   PSI = 289.23    PSIDOT =   71.03   PHITOT =  21.04
                  FF12 = 29.571    FF23 =  9.053   FF34 =  3.006
VP=  -4.539   VS= 135.614

    IMPACT

                 PHI= 196.043   PHIDOT= 431.204   PSI= 289.233   PSIDOT=-708.674   PHITOT =  21.043
VP=  45.287   VS=  45.287

    COUPLED MOTION
    T =  .00129   PHI = 196.04    PHIDOT = 431.20   G =-.0158   GDOT =103.50   PSID = 289.22   PSIDOT = -708.82   PHITOT =  21.04
                  F34 = 3.6907    F23 =10.0902   F12 =31.8141   PN = 1.1379    PNPSI = 1.1379   DPHI2 =  -.1652E+06
    T =  .00130   PHI = 196.29    PHIDOT = 429.44   G =-.0148   GDOT =104.20   PSID = 288.81   PSIDOT = -718.89   PHITOT =  21.29
                  F34 = 3.2957    F23 =10.1231   F12 =31.8675   PN = 1.1157    PNPSI = 1.1157   DPHI2 =  -.2307E+06
    T =  .00131   PHI = 196.53    PHIDOT = 427.15   G =-.0137   GDOT =104.80   PSID = 288.39   PSIDOT = -728.36   PHITOT =  21.53
                  F34 = 3.3008    F23 =10.1323   F12 =31.8883   PN = 1.1157    PNPSI = 1.1157   DPHI2 =  -.2633E+06
    T =  .00131   PHI = 196.60    PHIDOT = 426.27   G =-.0135   GDOT =104.87   PSID = 288.29   PSIDOT = -730.23   PHITOT =  21.60
                  F34 = 3.5554    F23 =11.2943   F12 =31.9644   PN = 1.0438    PNPSI = 1.0438   DPHI2 =  -.3641E+06
    T =  .00131   PHI = 196.66    PHIDOT = 425.33   G =-.0132   GDOT =104.94   PSID = 288.18   PSIDOT = -732.03   PHITOT =  21.66
                  F34 = 3.5566    F23 =11.2964   F12 =31.9688   PN = 1.0435    PNPSI = 1.0435   DPHI2 =  -.3706E+06
    T =  .00132   PHI = 196.72    PHIDOT = 424.41   G =-.0129   GDOT =105.01   PSID = 288.08   PSIDOT = -733.85   PHITOT =  21.72
```

Computer program SANDA3 (cont)

```
T =  .09064   PHI = 142.54   PHIDOT = 992.47   PSI =  70.69   PSIDOT = -934.56   PHITOT =3597.54
              FF12 = 44.581   FF23 = 15.148   FF34 =  4.060
T =  .09064   PHI = 142.62   PHIDOT =1000.95   PSI =  70.62   PSIDOT = -932.56   PHITOT =3597.62
              FF12 = 44.580   FF23 = 15.147   FF34 =  4.060
T =  .09064   PHI = 142.69   PHIDOT =1009.41   PSI =  70.56   PSIDOT = -930.56   PHITOT =3597.69
              FF12 = 44.601   FF23 = 15.188   FF34 =  4.079
T =  .09064   PHI = 142.76   PHIDOT =1017.86   PSI =  70.49   PSIDOT = -928.56   PHITOT =3597.76
              FF12 = 44.600   FF23 = 15.188   FF34 =  4.079
T =  .09065   PHI = 142.83   PHIDOT =1026.29   PSI =  70.42   PSIDOT = -926.56   PHITOT =3597.83
              FF12 = 44.621   FF23 = 15.230   FF34 =  4.099
T =  .09065   PHI = 142.91   PHIDOT =1034.70   PSI =  70.36   PSIDOT = -924.56   PHITOT =3597.91
              FF12 = 44.620   FF23 = 15.229   FF34 =  4.099
T =  .09065   PHI = 142.98   PHIDOT =1043.09   PSI =  70.29   PSIDOT = -922.56   PHITOT =3597.98
              FF12 = 44.643   FF23 = 15.272   FF34 =  4.119
T =  .09065   PHI = 143.06   PHIDOT =1051.46   PSI =  70.23   PSIDOT = -920.56   PHITOT =3598.06
              FF12 = 44.642   FF23 = 15.272   FF34 =  4.119
T =  .09065   PHI = 143.13   PHIDOT =1059.81   PSI =  70.16   PSIDOT = -918.56   PHITOT =3598.13
              FF12 = 44.721   FF23 = 15.344   FF34 =  4.594
T =  .09065   PHI = 143.21   PHIDOT =1068.15   PSI =  70.09   PSIDOT = -916.56   PHITOT =3598.21
              FF12 = 44.720   FF23 = 15.344   FF34 =  4.594
T =  .09065   PHI = 143.29   PHIDOT =1076.38   PSI =  70.03   PSIDOT = -914.56   PHITOT =3598.29
              FF12 = 44.664   FF23 = 15.348   FF34 =  4.618
T =  .09065   PHI = 143.36   PHIDOT =1084.68   PSI =  69.96   PSIDOT = -912.56   PHITOT =3598.36
              FF12 = 44.664   FF23 = 15.348   FF34 =  4.618
T =  .09066   PHI = 143.44   PHIDOT =1093.06   PSI =  69.90   PSIDOT = -910.56   PHITOT =3598.44
              FF12 = 44.607   FF23 = 15.351   FF34 =  4.642
T =  .09066   PHI = 143.52   PHIDOT =1101.51   PSI =  69.83   PSIDOT = -908.56   PHITOT =3598.52
              FF12 = 44.606   FF23 = 15.351   FF34 =  4.642
T =  .09066   PHI = 143.60   PHIDOT =1110.05   PSI =  69.77   PSIDOT = -906.56   PHITOT =3598.60
              FF12 = 44.547   FF23 = 15.355   FF34 =  4.667
T =  .09066   PHI = 143.68   PHIDOT =1118.66   PSI =  69.70   PSIDOT = -904.57   PHITOT =3598.68
              FF12 = 44.546   FF23 = 15.354   FF34 =  4.667
T =  .09066   PHI = 143.76   PHIDOT =1127.36   PSI =  69.64   PSIDOT = -902.57   PHITOT =3598.76
              FF12 = 44.486   FF23 = 15.357   FF34 =  4.693
T =  .09066   PHI = 143.94   PHIDOT =1136.13   PSI =  69.57   PSIDOT = -900.57   PHITOT =3598.84
              FF12 = 44.485   FF23 = 15.357   FF34 =  4.692
T =  .09066   PHI = 143.92   PHIDOT =1144.99   PSI =  69.51   PSIDOT = -898.57   PHITOT =3598.92
              FF12 = 44.424   FF23 = 15.360   FF34 =  4.718
T =  .09066   PHI = 144.00   PHIDOT =1153.92   PSI =  69.45   PSIDOT = -896.57   PHITOT =3599.00
              FF12 = 44.423   FF23 = 15.360   FF34 =  4.718
T =  .09067   PHI = 144.09   PHIDOT =1162.96   PSI =  69.38   PSIDOT = -894.57   PHITOT =3599.09
              FF12 = 44.361   FF23 = 15.363   FF34 =  4.744
T =  .09067   PHI = 144.17   PHIDOT =1172.06   PSI =  69.32   PSIDOT = -892.57   PHITOT =3599.17
              FF12 = 44.360   FF23 = 15.362   FF34 =  4.744
T =  .09067   PHI = 144.26   PHIDOT =1181.26   PSI =  69.25   PSIDOT = -890.57   PHITOT =3599.26
              FF12 = 44.352   FF23 = 15.394   FF34 =  4.297
T =  .09067   PHI = 144.34   PHIDOT =1190.47   PSI =  69.19   PSIDOT = -888.57   PHITOT =3599.34
              FF12 = 44.351   FF23 = 15.394   FF34 =  4.297
T =  .09067   PHI = 144.43   PHIDOT =1199.64   PSI =  69.13   PSIDOT = -886.57   PHITOT =3599.43
              FF12 = 44.377   FF23 = 15.444   FF34 =  4.320
T =  .09067   PHI = 144.51   PHIDOT =1208.80   PSI =  69.06   PSIDOT = -884.57   PHITOT =3599.51
              FF12 = 44.376   FF23 = 15.443   FF34 =  4.320
T =  .09067   PHI = 144.60   PHIDOT =1217.93   PSI =  69.00   PSIDOT = -882.57   PHITOT =3599.60
              FF12 = 44.403   FF23 = 15.495   FF34 =  4.344
T =  .09067   PHI = 144.69   PHIDOT =1227.04   PSI =  68.94   PSIDOT = -880.57   PHITOT =3599.69
              FF12 = 44.402   FF23 = 15.494   FF34 =  4.344
T =  .09068   PHI = 144.77   PHIDOT =1236.13   PSI =  68.87   PSIDOT = -878.57   PHITOT =3599.77
              FF12 = 44.430   FF23 = 15.546   FF34 =  4.369
T =  .09068   PHI = 144.86   PHIDOT =1245.19   PSI =  68.81   PSIDOT = -876.57   PHITOT =3599.86
              FF12 = 44.429   FF23 = 15.546   FF34 =  4.368
T =  .09068   PHI = 144.95   PHIDOT =1254.23   PSI =  68.75   PSIDOT = -874.57   PHITOT =3599.95
```

Computer program SANDA3 (cont)

```
              FF12 = 44.457   FF23 = 15.599   FF34 =  4.393
T =  .09068   PHI = 145.04   PHIDOT =1263.25   PSI =  68.69   PSIDOT = -872.57   PHITOT =3600.04
              FF12 = 44.456   FF23 = 15.599   FF34 =  4.393

F34MAX =  7.32

F23MAX = 20.98

F12 MAX = 54.41

FF34MAX =  5.84

FF23MAX = 18.58

FF12MAX = 49.97

PNMAX =  2.28

TURNS = 45.34
```

APPENDIX D

COMPUTER PROGRAM SANDA2

Computer program SANDA2


```
      PROGRAM SANDA2(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
     1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
     2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
     3HO3,RHOP,J1,J2,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE
     4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
     5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
     623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
      DIMENSION AUX(8,2), AUX2(8,4), PRMT(5), PHI(2), DPHI(2), X(4), DX(
     14)
      REAL M1,M2,M3,MP,I1,I2,I3,IP,LAMBDA,K,N31,N32,J1,J2,NG1,NG2,NP2,NP
     13,MU,MU1
      EXTERNAL FCT,OUTP,FCTF,OUTPF
C
C     READ IN AND WRITE DATA
C
      READ (5,22) A,B,C,R,ALPHA,CONFIG
      WRITE (6,23) A,B,C,R,ALPHA,CONFIG
      READ (5,24) EREST,LAMBDA,DELTA
      WRITE (6,25) EREST,LAMBDA,DELTA
      READ (5,26) M1,M2,M3,MP
      WRITE (6,27) M1,M2,M3,MP
      READ (5,26) I1,I2,I3,IP
      WRITE (6,28) I1,I2,I3,IP
      READ (5,29) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MU1
      WRITE (6,30) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MU1
      READ (5,31) PSUBD1,PSUBD2,NG1,NG2,NP2,NP3,CAPRP1,CAPRP2,RP2,RP3,TH
     1ETA1,THETA2
      WRITE (6,34) PSUBD1,PSUBD2,NG1,NG2,NP2,NP3,CAPRP1,CAPRP2,RP2,RP3,T
     1HETA1,THETA2
      READ (5,32) R1,R2,R3,R4
      WRITE (6,35) R1,R2,R3,R4
      READ (5,24) RHO1,RHO2,RHO3
      WRITE (6,36) RHO1,RHO2,RHO3
      READ (5,32) CAPRB1,CAPRB2,RB2,RB3
      WRITE (6,37) CAPRB1,CAPRB2,RB2,RB3
      READ (5,32) CAPRO1,CAPRO2,RO2,RO3
      WRITE (6,38) CAPRO1,CAPRO2,RO2,RO3
      READ (5,33) J1,J2
      WRITE (6,39) J1,J2
C
C     INITIALIZATION OF PARAMETERS AND CONVERSION TO RADIANS
C
      TIME=0.
      PHITOT=0.
      PHIPR=PHID
      DPHI2=0.
      DPSI2=0.
      F23MAX=0.
      F12MAX=0.
      FF23MAX=0.
      FF12MAX=0.
      PNMAX=0.
      PI=3.14159
      ZZ=PI/180.
      OMEGA=RPM*2.*PI/60.
```


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```
      OM2=OMEGA*OMEGA                                                    A  58
      PHI1C=PHI1CD*ZZ                                                    A  59
      PSICC=PSICCD*ZZ                                                    A  60
      PSIC=PSICC                                                         A  61
      ALPHR=ALPHA*ZZ                                                     A  62
C                                                                        A  63
C     DETERMINATION OF SIGNUM FUNCTION S6                                A  64
C                                                                        A  65
      IF (CONFIG.EQ.1.) S6=1.                                            A  66
      IF (CONFIG.EQ.2.) S6=-1.                                           A  67
C                                                                        A  68
C     COMPUTATION OF GEAR RATIOS                                         A  69
C                                                                        A  70
      N31=NP2*NP3/(NG1*NG2)                                              A  71
      N32=-NP3/NG2                                                       A  72
C                                                                        A  73
C     COMPUTATION OF GAMMAS AND BETAS                                    A  74
C                                                                        A  75
      GAMMA2=S6*ACOS((R1*R1+R2*R2-(CAPRP1+RP2)**2)/(2.*R1*R2))           A  76
      GAMA3P=ACOS((R2*R2+R3*R3-(CAPRP2+RP3)**2)/(2.*R2*R3))              A  77
      GAMMA3=GAMMA2+S6*GAMA3P                                            A  78
      GAMA4P=ACOS((R3*R3+R4*R4-A*A)/(2.*R3*R4))                          A  79
      GAMMA4=GAMMA3+S6*GAMA4P                                            A  80
      GAMMA2D=GAMMA2/ZZ                                                  A  81
      GAMMA3D=GAMMA3/ZZ                                                  A  82
      GAMMA4D=GAMMA4/ZZ                                                  A  83
      DELTA2=ACOS(((CAPRP1+RP2)**2+R1*R1-R2*R2)/(2.*R1*(CAPRP1+RP2)))    A  84
      DELTA3=ACOS(((CAPRP2+RP3)**2+R2*R2-R3*R3)/(2.*R2*(CAPRP2+RP3)))    A  85
      DELTA4=ACOS((A*A+R3*R3-R4*R4)/(2.*A*R3))                           A  86
      BETA1=PI-S6*DELTA2                                                 A  87
      BETA2=GAMMA2+PI-S6*DELTA3                                          A  88
      BETA3=GAMMA3+PI-S6*DELTA4                                          A  89
      IF (CONFIG.EQ.1.) GAMAPP=DELTA4+GAMA4P                             A  90
      IF (CONFIG.EQ.2.) GAMAPP=2.*PI-DELTA4-GAMA4P                       A  91
      BETA1D=BETA1/ZZ                                                    A  92
      BETA2D=BETA2/ZZ                                                    A  93
      BETA3D=BETA3/ZZ                                                    A  94
      WRITE (6,40) BETA1D,BETA2D,BETA3D,GAMMA2D,GAMMA3D,GAMMA4D          A  95
C                                                                        A  96
C     CONVERSION OF PRESSURE ANGLES TO RADIANS                           A  97
C                                                                        A  98
      THETA1=THETA1*ZZ                                                   A  99
      THETA2=THETA2*ZZ                                                   A 100
C                                                                        A 101
C     COMPUTATION OF CENTRIFUGAL FORCES                                  A 102
C                                                                        A 103
      T2=M2*R2*OM2                                                       A 104
      T3=M3*R3*OM2                                                       A 105
C                                                                        A 106
C     DETERMINATION OF GEAR TRAIN CONSTANTS                              A 107
C                                                                        A 108
      TEST1=TAN(THETA1)                                                  A 109
      TEST2=TAN(THETA2)                                                  A 110
      D1=(CAPRB1+RB2)*TAN(THETA1)                                        A 111
      D2=(CAPRB2+RB3)*TAN(THETA2)                                        A 112
C                                                                        A 113
C     DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS     A 114
```

```
      C
            CALL ALFA (CAPRB1,RB2,THETA1,CAPRO1,RO2,AL1IN,AL1FIN)
            CALL ALFA (CAPRB2,RB3,THETA2,CAPRO2,RO3,AL2IN,AL2FIN)
      C
      C     INITIALIZATION OF ALPHAS
      C
            ALPHA1=AL1IN+(AL1FIN-AL1IN)*J1
            ALPHA2=AL2IN+(AL2FIN-AL2IN)*J2
      C
      C     DATA FOR RUNGE KUTTA
      C
            PRMT(2)=3.
            PRMT(4)=.01
            NDIM=2
            NDIM2=4
            PHI(1)=PHID*ZZ
            PHI(2)=0.
      C
      C     COUPLED MOTION
      C
          1 PRMT(1)=TIME
            PRMT(3)=.00001
            DPHI(1)=.5
            DPHI(2)=.5
            IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 2
            WRITE (6,41)
          2 CALL RKGS (PRMT,PHI,DPHI,NDIM,IHLF,FCT,OUTP,AUX)
            IF (PHITOT.GE.PHICUTD) GO TO 21
      C
      C     TEST FOR ENTRANCE OR EXIT ACTION
      C
            IF (G.LE.0.) GO TO 5
            PHID=PHI(1)/ZZ
            IF (PHID.GE.135.00.AND.PHID.LE.160.) GO TO 3
            GO TO 4
          3 PHI(1)=PHI(1)+DELTA*ZZ
            PHIPR=PHI(1)/ZZ
            PSI=PSI+2.*PI-LAMBDA*ZZ
            PSIC=PSICC+LAMBDA*ZZ
            GO TO 5
          4 PHI(1)=PHI(1)-DELTA*ZZ*2.
            PHIPP=PHI(1)/ZZ
            PSI=PSI-2.*PI+LAMBDA*ZZ
            PSIC=PSICC
      C
      C     FREE MOTION
      C
          5 PRMT(1)=TIME
            X(1)=PHI(1)
            X(2)=PHI(2)
            X(3)=PSI
            X(4)=DPSI
            DX(1)=.25
            DX(2)=.25
            DX(3)=.25
            DX(4)=.25
            PRMT(3)=.00001
```

```
      IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 6
      WRITE (6,42)
    6 CALL RKGS (PRMT,X,DX,NDIM2,IHLF,FCTF,OUTPF,AUX2)
      IF (PHITOT.GE.PHICUTD) GO TO 21
      PHI(1)=X(1)
      PHI(2)=X(2)
      H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
      K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(
     1PHI(1)-ALPHR)
      GONE=(-H+SQRT(H*H-4.*K))/2.
      GTWO=(-H-SQRT(H*H-4.*K))/2.
      IF (ABS(GONE).LT.ABS(GTWO)) GO TO 7
      G=GTWO
      GO TO 8
    7 G=GONE
    8 PHID=PHI(1)/ZZ
      IF (GP.LT.0.) GO TO 11
      IF (PHID.GE.135.0.AND.PHID.LE.160.) GO TO 9
      GO TO 10
    9 PHI(1)=PHI(1)+DELTA*ZZ
      PHIPR=PHI(1)/ZZ
      PSI=PSI+2.*PI-LAMBDA*ZZ
      PSIC=PSICC+LAMBDA*ZZ
      GO TO 5
   10 PHI(1)=PHI(1)-DELTA*ZZ*2.
      PHIPR=PHI(1)/ZZ
      PSI=PSI-2.*PI+LAMBDA*ZZ
      PSIC=PSICC
      GO TO 5
   11 IF (PHID.LE.160.0) GO TO 13
C
C     EXIT ACTION
C
C     COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION
C
      AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 12
      WRITE (6,43) VP,VS
C
C     EXIT ACTION TESTS
C
   12 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 15
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15
      IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
C
C     COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
C
   13 AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
```

Computer program SANDA2 (cont)

```
PROGRAM SANDA2     74/74    OPT=1                        FTN 4.8+508        08/07/81  13.56.05        PAGE      5

          VP=DONE*DPSI
          VS=AONE*PHI(2)
          IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 14
          WRITE (6,43) VP,VS
C
C         ENTRANCE ACTION
C
       14 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
          IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
          IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 15
          IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
          IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 15
          IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
          IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 15
          IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
C
C         IMPACT
C
       15 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)
          H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))
          K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*
         1SIN(PHI(1)-ALPHR)
          GONE=(-H+SQRT(H**2-4.*K))/2.
          GTWO=(-H-SQRT(H**2-4.*K))/2.
          IF (ABS(GONE).LT.ABS(GTWO)) GO TO 16
          G=GTWO
          GO TO 17
       16 G=GONE
       17 IF (TIME.GT.5.0) GO TO 21
C
C         TEST FOR EXIT ACTION
C
          PHID=PHI(1)/ZZ
          IF (PHID.LE.160.0) GO TO 19
C
C         EXIT ACTION
C
C         COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION
          AONE=B*COS(ALPHR)+G
          DONE=C*COS(PHI(1)-ALPHR-PSI)
          VP=DONE*DPSI
          VS=AONE*PHI(2)
          IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 18
          WRITE (6,43) VP,VS
       18 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C         EXIT ACTION TESTS
C
          IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1
          IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
          IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
          IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
          IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
          IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
          IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
          IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
C
```

```
C     COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
C
   19 AONE=B*COS(ALPHR)+G
      DONE=C*COS(PHI(1)-ALPHR-PSI)
      VP=DONE*DPSI
      VS=AONE*PHI(2)
      IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 20
      WRITE (6,43) VP,VS
   20 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
C
C     ENTRANCE ACTION TESTS
C
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
      IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
   21 TURNS=TIME*RPM/60.
      WRITE (6,44) F23MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,TURNS
      STOP
C
C
C
   22 FORMAT (6F10.5)
   23 FORMAT (1H1,5X,2HA=,F13.5,5X,2HB=,F13.5,5X,2HC=,F13.5,5X,2HR=,F13.
     15,5X,6HALPHA=,F9.4,5X,14HCONFIGURATION=,F3.0/)
   24 FORMAT (3F10.5)
   25 FORMAT (1H ,5X,6HEREST=,F5.2,3X,7HLAMBDA=,F8.3,3X,6HDELTA=,F8.3/)
   26 FORMAT (4E12.5)
   27 FORMAT (1H ,5X,4HM1 =,E15.5,3X,4HM2 =,E15.5,3X,4HM3 =,E15.5,3X,4HM
     1P =,E15.5/)
   28 FORMAT (1H ,5X,4HI1 =,E15.5,3X,4HI2 =,E15.5,3X,4HI3 =,E15.5,3X,4HI
     1P =,E15.5/)
   29 FORMAT (7F10.4/3F10.4)
   30 FORMAT (6X,5HRC1 =,F7.4,3X,5HRCP =,F7.4,3X,6HRHOP =,F7.4,3X,5HRPM
     1=,F6.0,3X,8HPHI1CD =,F9.4,3X,8HPSICCD =,F9.4,3X,6HPHID =,F9.4//6X,
     29HPHICUTD =,F6.0//6X,4HMU =,F4.2,3X,5HMU1 =,F4.2/)
   31 FORMAT (2F10.4/4F10.0/4F10.5/2F10.4)
   32 FORMAT (4F10.4)
   33 FORMAT (2F10.2)
   34 FORMAT (1H ,5X,8HPSUBD1 =,F5.1,3X,8HPSUBD2 =,F5.1//6X,5HNG1 =,F4.0
     1,3X,5HNG2 =,F4.0,3X,5HNP2 =,F4.0,3X,5HNP3 =,F4.0//6X,8HCAPRP1 =,F8
     2.5,3X,8HCAPRP2 =,F8.5//6X,5HRP2 =,F8.5,3X,5HRP3 =,F8.5//6X,8HTHETA
     31 =,F8.3,3X,8HTHETA2 =,F8.3/)
   35 FORMAT (6X,4HR1 =,F7.5,3X,4HR2 =,F7.5,3X,4HR3 =,F7.5,3X,4HR4 =,F7.
     15/)
   36 FORMAT (6X,6HRHO1 =,F7.5,3X,6HRHO2 =,F7.5,3X,6HRHO3 =,F7.5/)
   37 FORMAT (6X,8HCAPRB1 =,F7.5,3X,8HCAPRB2 =,F7.5,3X,5HRB2 =,F7.5,3X,5
     1HRB3 =,F7.5/)
   38 FORMAT (6X,8HCAPRO1 =,F7.5,3X,8HCAPRO2 =,F7.5,3X,5HRO2 =,F7.5,3X,5
     1HRO3 =,F7.5/)
   39 FORMAT (1H0,5X,4HJ1 =,F4.2,3X,4HJ2 =,F4.2/)
   40 FORMAT (6X,8HBETA1D =,F7.2,3X,8HBETA2D =,F7.2,3X,8HBETA3D =,F7.2/6
     1X,9HGAMMA2D =,F7.2,3X,9HGAMMA3D =,F7.2,3X,9HGAMMA4D =,F7.2/)
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Computer program SANDA2 (cont)

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PROGRAM SANDA2      74/74    OPT=1                    FTN 4.8+508        08/07/81  13.56.05        PAGE     7

          41 FORMAT (1H0,5X,14HCOUPLED MOTION)
          42 FORMAT (1H0,5X,11HFREE MOTION//)
          43 FORMAT (4H0VP=,F8.3,3X,3HVS=,F8.3)
          44 FORMAT (1H0,6X,8HF23MAX =,F6.2/1H0,6X,8HF12MAX =,F6.2/1H0,6X,9HFF2
            13MAX =,F6.2/1H0,6X,9HFF12MAX =,F6.2/1H0,6X,7HPNMAX =,F6.2/1H0,6X,6
            2HTURNS=,F6.2)
             END
```

Computer program SANDA2 (cont)

```
SUBROUTINE IMPACT      74/74   OPT=1                      FTN 4.8+508        08/07/81   13.56.05        PAGE     1

          SUBROUTINE IMPACT (PHI,DPHI,PSI,DPSI)                                   B   1
          COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE      B   2
         1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N      B   3
         2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R      B   4
         3HO3,RHOP,J1,J2,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE      B   5
         4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH      B   6
         5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F      B   7
         623MAX,F12MAX,FF23MAX,FF12MAX,FNMAX,PHICUTD                              B   8
          REAL I1,I2,I3,IP,LAMBDA,N31,N32,ISTOT,K                                 B   9
          ISTOT=I3+I2*N32*N32+I1*N31*N31                                          B  10
          H=2.*(B*COS(ALPHR)+A*COS(PHI-ALPHR))                                    B  11
          K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI)-2.*A*R*SIN      B  12
         1(PHI-ALPHR)                                                             B  13
          GONE=(-H+SQRT(H**2-4.*K))/2.                                            B  14
          GTWO=(-H-SQRT(H**2-4.*K))/2.                                            B  15
          IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1                                     B  16
          G=GTWO                                                                  B  17
          GO TO 2                                                                 B  18
        1 G=GONE                                                                  B  19
        2 AONE=B*COS(ALPHR)+G                                                     B  20
          DONE=C*COS(PHI-ALPHR-PSI)                                               B  21
          DPHIIN=DPHI                                                             B  22
          DPHI=(IP*AONE*DPSI+ISTOT*DONE*DPHI+IP*AONE*EREST/DONE*(DPSI*DONE-D      B  23
         1PHI*AONE))/(IP*AONE**2/DONE+ISTOT*DONE)                                 B  24
          DPSI=(DPHI*AONE-EREST*(DPSI*DONE-DPHIIN*AONE))/DONE                     B  25
          PHID=PHI/ZZ                                                             B  26
          PSID=PSI/ZZ                                                             B  27
          IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 3                          B  28
          WRITE (6,4)                                                             B  29
          WRITE (6,5) PHID,DPHI,PSID,DPSI,PHITOT                                  B  30
        3 RETURN                                                                  B  31
    C                                                                             B  32
    C                                                                             B  33
    C                                                                             B  34
        4 FORMAT (1H0,5X,6HIMPACT)                                                B  35
        5 FORMAT (1H0,18X,4HPHI=,F8.3,3X,7HPHIDOT=,F8.3,3X,4HPSI=,F8.3,3X,7H      B  36
         1PSIDOT=,F8.3,3X,8HPHITOT =,F8.3)                                        B  37
          END                                                                     B  38-
```

Computer program SANDA2 (cont)

```
SUBROUTINE FCT        74/74    OPT=1                    FTN 4.8+508         08/07/81   13.56.05         PAGE     1

      SUBROUTINE FCT (T,PHI,DPHI)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
     1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
     2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
     3HO3,RHOP,J1,J2,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE
     4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
     5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
     623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX
      DIMENSION PHI(2), DPHI(2)
      REAL M1,M2,M3,MP,I1,I2,I3,IP,K,I1R,N31,N32,MU,MU1,IPR
      PHID=PHI(1)/ZZ
      DELPHI=PHID-PHIPR
      PHIT=(PHITOT+DELPHI)*ZZ
      IN=1
      CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
     1,DONE,U,V,Z)
      CALL IN2 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
     12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
     2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
     330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
     43,AA44)
      IF (DPSI*DPSI2.GE.0.) IPR=IP+AA22
      IF (DPSI*DPSI2.LT.0.) IPR=IP-AA22
      IF (PHI(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (PHI(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      AA45=I3*AA18+IPR*AA17*U-(I2*N32-AA42*I1R*N31/AA31)*AA15*AA18/AA44
      AA46=IPR*AA17*V+AA17*AA21*Z*Z+AA15*AA18*AA34*AA42*N31*N31/(AA31*AA
     144)
      AA47=2.*OM2*AA17*AA20*Z/ABS(OMEGA)+AA15*AA18*AA33*AA42*N31/(AA31*A
     1A44)
      AA48=-AA15*AA18*AA32*AA42/(AA31*AA44)-AA15*AA18*AA43*T2/AA44-AA16*
     1AA18*T3-OM2*AA17*AA19
      AA49=AA15*AA18*AA35*AA42/(AA31*AA44)
      AA50=MP*RCP*R4*AA17*OM2
      DPHI(1)=PHI(2)
      DPHI(2)=(-AA46*PHI(2)*PHI(2)-AA47*PHI(2)+AA48-AA49*SIN(PHI1C+N31*(
     1PHITOT*ZZ+PHI(1)-PHIPR*ZZ))+AA50*SIN(GAMAPP-PSI-PSIC))/AA45
      RETURN
      END
```

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SUBROUTINE OUTP        74/74   OPT=1                    FTN 4.8+508        08/07/81  13.56.05        PAGE     1

      SUBROUTINE OUTP (T,PHI,DPHI,IHLF,NDIM,PRMT)
      REAL M1,M2,M3,MP,I1,I2,I3,IP,K,I1R,N31,N32,MU,MU1,IPR
      DIMENSION PHI(2), DPHI(2), PRMT(5)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
     1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
     2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
     3HO3,RHOP,J1,J2,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE
     4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
     5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
     623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
      PHID=PHI(1)/ZZ
      DELPHI=PHID-PHIPR
      PHIPR=PHID
      PHITOT=PHITOT+DELPHI
      PHIT=PHITOT*ZZ
      IN=0
      CALL KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BONE,CONE
     1,DONE,U,V,Z)
      CALL IN2 (PHI,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,AA1,AA
     12,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,A
     2A17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA
     330,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA4
     43,AA44)
      IF (DPSI*DPSI2.GE.0.) IPR=IP+AA22
      IF (DPSI*DPSI2.LT.0.) IPR=IP-AA22
      IF (PHI(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (PHI(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      AA45=I3*AA18+IPR*AA17*U-(I2*N32-AA42*I1R*N31/AA31)*AA15*AA18/AA44
      AA46=IPR*AA17*V+AA17*AA21*Z*Z+AA15*AA18*AA34*AA42*N31*N31/(AA31*AA
     144)
      AA47=2.*OM2*AA17*AA20*Z/ABS(OMEGA)+AA15*AA18*AA33*AA42*N31/(AA31*A
     1A44)
      AA48=-AA15*AA18*AA32*AA42/(AA31*AA44)-AA15*AA18*AA43*T2/AA44-AA16*
     1AA18*T3-OM2*AA17*AA19
      AA49=AA15*AA18*AA35*AA42/(AA31*AA44)
      AA50=MP*RCP*R4*AA17*OM2
      DPHI2=(-AA46*PHI(2)*PHI(2)-AA47*PHI(2)+AA48-AA49*SIN(PHI1C+N31*(PH
     1ITOT*ZZ+PHI(1)-PHIPR*ZZ))+AA50*SIN(GAMAPP-PSI-PSIC))/AA45
      DPSI2=U*DPHI2+V*PHI(2)*PHI(2)
C
C     COMPUTATION OF CONTACT FORCES
C
      F23=(-AA32*AA42/AA31-T2*AA43-AA33*AA42*N31*PHI(2)/AA31-AA42*AA34*N
     131*N31*PHI(2)*PHI(2)/AA31-AA35*AA42*SIN(PHI1C+N31*PHIT)/AA31+(I2*N
     232-AA42*I1R*N31/AA31)*DPHI2)/AA44
      F12=(F23*AA44+T2*AA43-I2*N32*DPHI2)/AA42
      PN=(-I3*DPHI2+F23*AA15-T3*AA16)/AA17
      IF (F23.GT.F23MAX) F23MAX=F23
      IF (F12.GT.F12MAX) F12MAX=F12
      IF (PN.GT.PNMAX) PNMAX=PN
      PNPSI=(IPR*DPSI2+AA21*DPSI*DPSI+2.*OM2*DPSI*AA20/ABS(OMEGA)+OM2*AA
     119-MP*RCP*R4*OM2*SIN(GAMAPP-PSI-PSIC))/AA18
C
C     TEST FOR CONTINUATION OF COUPLED MOTION
```

Computer program SANDA2 (cont)

```
SUBROUTINE OUTP       74/74   OPT=1                    FTN 4.8+508       08/07/81  13.56.05        PAGE     2

          C
               IF (.NOT.(G.LT.0..AND.PNPSI.GT.0.)) PRMT(5)=1.
          C
          C    WRITE OUTPUT
          C
               IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 1
               PSID=PSI/ZZ
               WRITE (6,2) T,PHID,PHI(2),G,GDOT,PSID,DPSI,PHITOT,F23,F12,PN,PNPSI
              1,DPHI2
             1 TIME=T
               IF(PHITOT.GE.PHICUTD)PRMT(5)=1.
               RETURN
          C
          C
             2 FORMAT (6X,3HT =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,3HG =,
              1F6.4,3X,6HGDOT =,F6.2,3X,6HPSID =,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHI
              2TOT =,F7.2/20X,5HF23 =,F7.4,3X,5HF12 =,F7.4,3X,4HPN =,F7.4,3X,7HPN
              3PSI =,F7.4,3X,7HDPHI2 =,E12.4)
               END
```

```
      SUBROUTINE FCTF (T,X,DX)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
     1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
     2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
     3HO3,PHOP,J1,J2,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE
     4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
     5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
     623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      DIMENSION X(4), DX(4), PRMT(5)
      REAL M1,M2,M3,MP,I1,I2,I3,IP,I1R,N31,N32,MU,MU1,IPR
      PHID=X(1)/ZZ
      DELPHI=PHID-PHIPR
      PHIT=(PHITOT+DELPHI)*ZZ
      IN=1
      CALL IN2 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
     1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
     219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
     32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44)
      IF (X(4)*DPSI2.GE.0.) IPR=IP+AA22
      IF (X(4)*DPSI2.LT.0.) IPR=IP-AA22
      IF (X(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (X(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      IF (IPR.EQ.0.) WRITE (6,1)
      AA51=IPR
      AA52=2.*OM2*AA20/ABS(OMEGA)
      AA53=OM2*AA19
      AA54=OM2*MP*RCP*R4
      AA55=I3-AA15*N32*I2/AA44+AA15*AA42*I1R*N31/(AA31*AA44)
      AA56=AA15*AA34*AA42*N31*N31/(AA31*AA44)
      AA57=AA15*AA33*AA42*N31/(AA31*AA44)
      AA58=-AA16*T3-AA15*AA43*T2/AA44-AA15*AA32*AA42/(AA31*AA44)
      AA59=AA15*AA35*AA42/(AA31*AA44)
      DX(1)=X(2)
      DX(3)=X(4)
      DX(2)=(-AA56*X(2)*X(2)-AA57*X(2)+AA58-AA59*SIN(PHI1C+N31*(PHITOT*Z
     1Z+X(1)-PHIPR*ZZ)))/AA55
      DX(4)=(-AA21*X(4)*X(4)-AA52*X(4)-AA53+AA54*SIN(GAMAPP-X(3)-PSIC))/
     1AA51
      RETURN
C
C
    1 FORMAT (40HOIPR EQUALS ZERO - SIMULATION TERMINATED)
      END
```

Computer program SANDA2 (cont)

```
SUBROUTINE OUTPF       74/74    OPT=1                    FTN 4.8+508        08/07/81   13.56.05        PAGE      1

      SUBROUTINE OUTPF (T,X,DX,IHLF,NDIM,PRMT)
      COMMON A,B,C,R,ALPHR,F1,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
     1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
     2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
     3HO3,RHOP,J1,J2,GAMMA2,GAMA3P,GAYMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE
     4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
     5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
     6F23MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      REAL M1,M2,M3,MP,I1,I2,I3,IP,I1R,N31,N32,MU,MU1,IPR
      DIMENSION X(4), DX(4), PRMT(5)
      COMMON /ZETA/ PSI,TIME,G,DPSI,GP
      PHID=X(1)/ZZ
      PSID=X(3)/ZZ
      DELPHI=PHID-PHIPR
      PHITOT=PHITOT+DELPHI
      PHIT=PHITOT*ZZ
      PHIPR=PHID
      IN=0
      CALL IN2 (X,PHIT,DELPHI,0.,X(3),X(4),0.,0.,0.,0.,AA1,AA2,AA3,AA4,A
     1A5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16,AA17,AA18,AA
     219,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,AA30,AA31,AA3
     32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,AA43,AA44)
      IF (X(4)*DPSI2.GE.0.) IPR=IP+AA22
      IF (X(4)*DPSI2.LT.0.) IPR=IP-AA22
      IF (X(2)*DPHI2.GE.0.) I1R=I1+ABS(MU)*RHO1*(AA26+AA30)
      IF (X(2)*DPHI2.LT.0.) I1R=I1-ABS(MU)*RHO1*(AA26+AA30)
      IF (I1R.LT.0.) I1R=0.
      IF (IPR.LT.0.) IPR=0.
      AA51=IPR
      AA52=2.*OM2*AA20/ABS(OMEGA)
      AA53=OM2*AA19
      AA54=OM2*MP*RCP*R4
      AA55=I3-AA15*N32*I2/AA44+AA15*AA42+I1R*N31/(AA31*AA44)
      AA56=AA15*AA34*AA42*N31*N31/(AA31*AA44)
      AA57=AA15*AA33*AA42*N31/(AA31*AA44)
      AA58=-AA16*T3-AA15*AA43*T2/AA44-AA15*AA32*AA42/(AA31*AA44)
      AA59=AA15*AA35*AA42/(AA31*AA44)
      PSI=X(3)
      DPSI=X(4)
      DPSI2=(-AA21*X(4)*X(4)-AA52*X(4)-AA53+AA54*SIN(GAMAPP-X(3)-PSIC))/
     1AA51
      DPHI2=(-AA56*X(2)*X(2)-AA57*X(2)+AA58-AA59*SIN(PHI1C+N31*(PHITOT*Z
     1Z+X(1)-PHIPR*ZZ)))/AA55
C
C     COMPUTATION OF CONTACT FORCES
C
      FF23=(I3*DPHI2+T3*AA16)/AA15
      FF12=(FF23*AA44+T2*AA43-I2*N32*DPHI2)/AA42
      IF (FF23.GT.FF23MAX) FF23MAX=FF23
      IF (FF12.GT.FF12MAX) FF12MAX=FF12
C
C     WRITE OUTPUT
C
      IF (PHITOT.GT.55..AND.PHITOT.LT.1765.) GO TO 1
      WRITE (6,4) T,PHID,X(2),PSID,X(4),PHITOT,FF12,FF23
    1 IF (T.EQ.TIME) GO TO 3
C
```

```
SUBROUTINE OUTPF      74/74    OPT=1                    FTN 4.8+508       08/07/81  13.56.05        PAGE    2

      C     CHECK FOR CONTINUED FREE MOTION
      C
            F=A*SIN(X(1)-ALPHR)-B*SIN(ALPHR)-C*SIN(X(1)-ALPHR-PSI)-R
            GP=C*COS(X(1)-ALPHR-PSI)-B*COS(ALPHR)-A*COS(X(1)-ALPHR)
            IF (F.GT.0.) GO TO 2
            PRMT(5)=1.
            GO TO 3
          2 IF (GP.GT.0.) PRMT(5)=1.
          3 TIME=T
            IF(PHITOT.GE.PHICUTD)PRMT(5)=1.
            RETURN
      C
      C
          4 FORMAT (6X,3HT =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI
           1=,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F7.2/20X,6HFF12 =,F7.3,3X,
           26HFF23 =,F7.3)
            END
```

Computer program SANDA2 (cont)

```
SUBROUTINE KINEM       74/74    OPT=1                    FTN 4.8+508         08/07/81   13.56.05          PAGE      1

           SUBROUTINE KINEM (A,B,ALPHR,PHI,R,C,G,P,Q,S,GDOT,PSI,DPSI,AONE,BON   G   1
          1E,CONE,DONE,U,V,Z)                                                   G   2
           DIMENSION PHI(2)                                                     G   3
           REAL K                                                               G   4
           PI=3.14159                                                           G   5
           H=2.*(B*COS(ALPHR)+A*COS(PHI(1)-ALPHR))                              G   6
           K=A*A+B*B+R*R-C*C+2.*B*R*SIN(ALPHR)+2.*A*B*COS(PHI(1))-2.*A*R*SIN(   G   7
          1PHI(1)-ALPHR)                                                        G   8
           GONE=(-H+SQRT(H*H-4.*K))/2.                                          G   9
           GTWO=(-H-SQRT(H*H-4.*K))/2.                                          G  10
           IF (ABS(GONE).LT.ABS(GTWO)) GO TO 1                                  G  11
           G=GTWO                                                               G  12
           GO TO 2                                                              G  13
         1 G=GONE                                                               G  14
         2 P=B*SIN(PHI(1))+G*SIN(PHI(1)-ALPHR)+R*COS(PHI(1)-ALPHR)              G  15
           Q=B*COS(PHI(1))+G*COS(PHI(1)-ALPHR)-R*SIN(PHI(1)-ALPHR)              G  16
           S=G+B*COS(ALPHR)+A*COS(PHI(1)-ALPHR)                                 G  17
           GDOT=PHI(2)*A*P/S                                                    G  18
           PSI=ASIN(P/C)                                                        G  19
           IF (PSI.LT.0.) GO TO 3                                               G  20
           GO TO 4                                                              G  21
         3 PSI=2.*PI-ABS(PSI)                                                   G  22
         4 DPSI=(Q*PHI(2)+GDOT*SIN(PHI(1)-ALPHR))/(C*COS(PSI))                  G  23
           AONE=B*COS(ALPHR)+G                                                  G  24
           BONE=B*SIN(ALPHR)                                                    G  25
           CONE=-(R+C*SIN(PHI(1)-ALPHR-PSI))                                    G  26
           DONE=C*COS(PHI(1)-ALPHR-PSI)                                         G  27
           Z=(Q+A*P/S*SIN(PHI(1)-ALPHR))/(C*COS(PSI))                           G  28
           U=(Q+SIN(PHI(1)-ALPHR)*P*A/S)/(C*COS(PSI))                           G  29
           V=(Q+A*P*SIN(PHI(1)-ALPHR)/S)**2*TAN(PSI)/(C**2*(COS(PSI))**2)+(1.   G  30
          1/(C*COS(PSI)))*(2.*A*P*COS(PHI(1)-ALPHR)/S-P+2.*A**2*P*(SIN(PHI(1)   G  31
          2-ALPHR))**2/S**2+A*Q*SIN(PHI(1)-ALPHR)/S-A**2*P**2*SIN(PHI(1)-ALPH   G  32
          3R)/S**3)                                                             G  33
           RETURN                                                               G  34
           END                                                                  G  35-
```

```
SUBROUTINE IN2        74/74   OPT=1                    FTN 4.8+508        08/07/81  13.56.05        PAGE    1

      SUBROUTINE IN2 (ZZZ,PHIT,DELPHI,GDOT,PSI,DPSI,AONE,BONE,CONE,DONE,
     1AA1,AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,
     2AA16,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA29,A
     3A29,AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA
     442,AA43,AA44)
      COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE
     1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N
     2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R
     3HO3,RHOP,J1,J2,GAMMA2,GAMA3P,GAMMA3,GAMA4P,GAMMA4,GAMAPP,DELTA2,DE
     4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH
     5A1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F
     623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PHICUTD
      DIMENSION ZZZ(4)
      REAL M1,M2,M3,MP,MU,MU1,N31,N32,I1
      PHI=ZZZ(1)
      DPHI=ZZZ(2)
      IF (DPHI.EQ.0.) GO TO 1
      MU=ABS(MU)*DPHI/ABS(DPHI)
    1 IF (IN.EQ.0) GO TO 2
C
C     UPDATE VALUES OF ALPHAS
C
      DELAL2=DELPHI*ZZ
      DELAL1=DELAL2*RB2/CAPRB1
      ALPHA1=ALPHA1+DELAL1
      ALPHA2=ALPHA2+DELAL2
      IF (ALPHA1.GT.AL1FIN) ALPHA1=AL1IN
      IF (ALPHA2.GT.AL2FIN) ALPHA2=AL2IN
C
C     DETERMINATION OF SIGNUMS
C
    2 IF (ALPHA1.LT.TEST1) S1=1.
      IF (ALPHA2.LT.TEST2) S2=1.
      IF (ALPHA1.EQ.TEST1) S1=0.
      IF (ALPHA2.EQ.TEST2) S2=0.
      IF (ALPHA1.GT.TEST1) S1=-1.
      IF (ALPHA2.GT.TEST2) S2=-1.
      IF (GDOT.NE.0.) GO TO 3
      S4=1.
      GO TO 4
    3 S4=GDOT/ABS(GDOT)
    4 IF (DPSI.NE.0.) GO TO 5
      S5=1.
      GO TO 6
    5 S5=DPSI/ABS(DPSI)
C
C     COMPUTATION OF A1 AND A2
C
    6 A1=ALPHA1*CAPRB1
      A2=ALPHA2*CAPRB2
      DENOM=1.+MU*MU
      DENOM1=1.+MU1*MU1
C
C     COMPUTATION OF AA1 TO AA44
C
      AA1=ABS((MU1*(S4-S5)*SIN(PHI-ALPHR)-(1.+S4*S5*MU1*MU1)*COS(PHI-ALP
     1HR))/DENOM1)
```

```
      AA2=ABS((MP*(R4*(SIN(GAMAPP)-MU1*S5*COS(GAMAPP))+RCP*(SIN(PSI+PSIC  H  58
     1)-MU1*S5*COS(PSI+PSIC))))/DENOM1)                                   H  59
      AA3=ABS((MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)       H  60
      AA4=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)       H  61
      AA5=ABS((MU1*(S4-S5)*COS(PHI-ALPHR)+(1.+S4*S5*MU1*MU1)*SIN(PHI-ALP  H  62
     1HR))/DENOM1)                                                        H  63
      AA6=ABS((MP*(-R4*(COS(GAMAPP)+MU1*S5*SIN(GAMAPP))-RCP*(COS(PSI+PSI  H  64
     1C)+MU1*S5*SIN(PSI+PSIC))))/DENOM1)                                  H  65
      AA7=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1)       H  66
      AA8=ABS((MP*RCP*(SIN(PSI+PSIC)-MU1*S5*COS(PSI+PSIC)))/DENOM1)       H  67
      AA9=ABS((-(MU1*S4-MU)*SIN(PHI-ALPHR+BETA3)+(1.+MU1*MU*S4)*COS(PHI-  H  68
     1ALPHR+BETA3))/DENOM)                                                H  69
      AA10=ABS((-MU*(1.-S2)*SIN(BETA2+THETA2)-(1.+MU*MU*S2)*COS(BETA2+TH  H  70
     1ETA2))/DENOM)                                                       H  71
      AA11=ABS((SIN(GAMMA3)-MU*COS(GAMMA3))/DENOM)                        H  72
      AA12=ABS(((1.+MU1*MU*S4)*SIN(PHI-ALPHR+BETA3)+(S4*MU1-MU)*COS(PHI-  H  73
     1ALPHR+BETA3))/DENOM)                                                H  74
      AA13=ABS((-(1.+MU*MU*S2)*SIN(BETA2+THETA2)+MU*(1.-S2)*COS(BETA2+TH  H  75
     1ETA2))/DENOM)                                                       H  76
      AA14=ABS((COS(GAMMA3)+MU*SIN(GAMMA3))/DENOM)                        H  77
      AA15=RB3-MU*(S2*(D2-A2)+RHO3*(AA10+AA13))                           H  78
      AA16=MU*RHO3*(AA11+AA14)                                            H  79
      AA17=AONE+MU1*S4*BONE+MU*RHO3*(AA9+AA12)                            H  80
      AA18=DONE+CONE*MU1*S4-RHOP*MU1*S5*(AA1+AA5)                         H  81
      AA19=RHOP*MU1*S5*(AA2+AA6)                                          H  82
      AA20=RHOP*MU1*(AA3+AA7)                                             H  83
      AA21=S5*AA20                                                        H  84
      AA22=RHOP*MU1*(AA4+AA8)                                             H  85
      AA23=ABS(((1.-MU*MU*S1)*SIN(BETA1-THETA1)-MU*(1.+S1)*COS(BETA1-THE  H  86
     1TA1))/DENOM)                                                        H  87
      AA24=ABS((M1*(R1+RC1*(COS(PHI1C+N31*PHIT)+MU*SIN(PHI1C+N31*PHIT)))  H  88
     1)/DENOM)                                                            H  89
      AA25=ABS((M1*RC1*(COS(PHI1C+N31*PHIT)+MU*SIN(PHI1C+N31*PHIT)))/DEN  H  90
     1OM)                                                                 H  91
      AA26=ABS((M1*RC1*(SIN(PHI1C+N31*PHIT)-MU*COS(PHI1C+N31*PHIT)))/DEN  H  92
     1OM)                                                                 H  93
      AA27=ABS((MU*(1.+S1)*SIN(BETA1-THETA1)+(1.-MU*MU*S1)*COS(BETA1-THE  H  94
     1TA1))/DENOM)                                                        H  95
      AA28=ABS((MU*M1*R1+M1*RC1*(MU*COS(PHI1C+N31*PHIT)-SIN(PHI1C+N31*PH  H  96
     1IT)))/DENOM)                                                        H  97
      AA29=ABS((M1*RC1*(MU*COS(PHI1C+N31*PHIT)-SIN(PHI1C+N31*PHIT)))/DEN  H  98
     1OM)                                                                 H  99
      AA30=ABS((M1*RC1*(MU*SIN(PHI1C+N31*PHIT)+COS(PHI1C+N31*PHIT)))/DEN  H 100
     1OM)                                                                 H 101
      AA31=CAPPB1-MU*S1*A1+MU*RHO1*(AA23+AA27)                            H 102
      AA32=OM2*RHO1*MU*(AA24+AA28)                                        H 103
      AA33=OM2/ABS(OMEGA)*2.*ABS(MU)*RHO1*(AA25+AA29)                     H 104
      AA34=MU*RHO1*(AA25+AA29)                                            H 105
      AA35=M1*R1*RC1*OM2                                                  H 106
      AA36=ABS((((1.-MU*MU*S2)*SIN(BETA2+THETA2)+MU*(1.+S2)*COS(BETA2+THE  H 107
     1TA2))/DENOM)                                                        H 108
      AA37=ABS(((1.+MU*MU*S1)*SIN(BETA1-THETA1)+MU*(1.-S1)*COS(BETA1-THE  H 109
     1TA1))/DENOM)                                                        H 110
      AA38=ABS((COS(GAMMA2)-MU*SIN(GAMMA2))/DENOM)                        H 111
      AA39=ABS((MU*(1.+S2)*SIN(BETA2+THETA2)-(1.-MU*MU*S2)*COS(BETA2+THE  H 112
     1TA2))/DENOM)                                                        H 113
      AA40=ABS((MU*(1.-S1)*SIN(BETA1-THETA1)-(1.+MU*MU*S1)*COS(BETA1-THE  H 114
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SUBROUTINE IN2        74/74    OPT=1                      FTN 4.8+508        08/07/81  13.56.05        PAGE     3

                   1TA1))/DENOM)                                                       H 115
                    AA41=ABS((MU*COS(GAMMA2)+SIN(GAMMA2))/DENOM)                       H 116
                    AA42=RB2-MU*(S1*(D1-A1)+RHO2*(AA37+AA40))                          H 117
                    AA43=MU*RHO2*(AA38+AA41)                                           H 118
                    AA44=CAPRB2-MU*(S2*A2-RHO2*(AA36+AA39))                            H 119
                    RETURN                                                             H 120
                    END                                                                H 121-
```

Computer program SANDA2 (cont)

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SUBROUTINE ALFA       74/74    OPT=1                         FTN 4.8+508        08/07/81  13.56.05         PAGE      1

                      SUBROUTINE ALFA (CAPRB,RB,THETA,CAPRO,RO,ALIN,ALFIN)
              C
              C       THIS SUBROUTINE COMPUTES THE INITIAL AND FINAL VALUES OF ALPHAS
              C
                      ALIN=((CAPRB+RB)*TAN(THETA)-SQRT(RO*RO-RB*RB))/CAPRB
                      ALFIN=SQRT(CAPRO*CAPRO-CAPRB*CAPRB)/CAPRB
                      RETURN
                      END
```

```
A=      .20970    B=      .19300    C=      .07680    R=      .01500    ALPHA=  52.0000    CONFIGURATION= 2.

EREST= 0.00   LAMBDA= 152.144   DELTA=  30.000

M1 =   .35310E-04   M2 =   .32260E-05   M3 =   .26560E-05   MP =   .24510E-05

I1 =   .33500E-05   I2 =   .37500E-07   I3 =   .24900E-07   IP =   .65720E-07

RC1 =  .1150   RCP = 0.0000   RHOP =  .0155   RPM =30000.   PHI1CD =-122.2300   PSICCD =   0.0000   PHID = 150.0000

PHICUTD = 1600.

MU = .15   MU1 = .15

PSUBD1 = 44.0   PSUBD2 = 63.5

NG1 = 41.   NG2 = 29.   NP2 =  6.   NP3 =  6.

CAPRP1 =  .46591   CAPRP2 =  .22835

RP2 =  .06818   RP3 =  .04724

THETA1 =  20.000   THETA2 =  20.000

R1 = .22500   R2 = .40800   R3 = .36800   R4 = .36100

RHO1 = .04650   RHO2 = .01550   RHO3 = .01550

CAPRB1 = .43781   CAPRB2 = .21458   RB2 = .06407   RB3 = .04439

CAPRO1 = .47388   CAPRO2 = .23387   RO2 = .09373   RO3 = .07321

J1 =0.00   J2 =0.00

BETA1D = 225.18   BETA2D = 129.80   BETA3D =  98.46
GAMMA2D =-111.79  GAMMA3D =-152.99  GAMMA4D =-186.41

COUPLED MOTION
T = 0.00000   PHI = 150.00   PHIDOT =    0.00   G =-.0221   GDOT =   0.00   PSID =  67.01   PSIDOT =    0.00   PHITOT =  -.00
              F23 = 3.7149   F12 =16.2589   PN =  .7247   PNPSI =  .7247   DPHI2 =   .1552E+06
T =   .00001  PHI = 150.00   PHIDOT =    1.55   G =-.0221   GDOT =    .35   PSID =  67.01   PSIDOT =    2.22   PHITOT =   .00
              F23 = 3.7151   F12 =16.2589   PN =  .7248   PNPSI =  .7248   DPHI2 =   .1553E+06
T =   .00002  PHI = 150.00   PHIDOT =    3.10   G =-.0221   GDOT =    .70   PSID =  67.01   PSIDOT =    4.45   PHITOT =   .00
              F23 = 3.7151   F12 =16.2589   PN =  .7248   PNPSI =  .7248   DPHI2 =   .1552E+06
T =   .00003  PHI = 150.00   PHIDOT =    4.66   G =-.0221   GDOT =   1.05   PSID =  67.02   PSIDOT =    6.67   PHITOT =   .00
              F23 = 3.7159   F12 =16.2590   PN =  .7255   PNPSI =  .7255   DPHI2 =   .1556E+06
T =   .00004  PHI = 150.01   PHIDOT =    6.21   G =-.0221   GDOT =   1.40   PSID =  67.02   PSIDOT =    8.90   PHITOT =   .01
              F23 = 3.7159   F12 =16.2590   PN =  .7254   PNPSI =  .7254   DPHI2 =   .1555E+06
T =   .00005  PHI = 150.01   PHIDOT =    7.77   G =-.0220   GDOT =   1.75   PSID =  67.03   PSIDOT =   11.13   PHITOT =   .01
              F23 = 3.7173   F12 =16.2592   PN =  .7265   PNPSI =  .7265   DPHI2 =   .1562E+06
T =   .00006  PHI = 150.02   PHIDOT =    9.33   G =-.0220   GDOT =   2.10   PSID =  67.03   PSIDOT =   13.37   PHITOT =   .02
              F23 = 3.7173   F12 =16.2593   PN =  .7265   PNPSI =  .7265   DPHI2 =   .1560E+06
T =   .00007  PHI = 150.02   PHIDOT =   10.89   G =-.0220   GDOT =   2.45   PSID =  67.04   PSIDOT =   15.61   PHITOT =   .02
              F23 = 3.7192   F12 =16.2595   PN =  .7281   PNPSI =  .7281   DPHI2 =   .1569E+06
T =   .00008  PHI = 150.03   PHIDOT =   12.46   G =-.0220   GDOT =   2.81   PSID =  67.05   PSIDOT =   17.86   PHITOT =   .03
              F23 = 3.7192   F12 =16.2596   PN =  .7280   PNPSI =  .7280   DPHI2 =   .1568E+06
T =   .00009  PHI = 150.04   PHIDOT =   14.03   G =-.0219   GDOT =   3.16   PSID =  67.06   PSIDOT =   20.11   PHITOT =   .04
              F23 = 3.7218   F12 =16.2601   PN =  .7301   PNPSI =  .7301   DPHI2 =   .1579E+06
T =   .00010  PHI = 150.04   PHIDOT =   15.60   G =-.0219   GDOT =   3.51   PSID =  67.07   PSIDOT =   22.38   PHITOT =   .04
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Computer program SANDA2 (cont)

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              F23 = 3.7218   F12 =16.2601   PN = .7299    PNPSI = .7299    DPHI2 =  .1577E+06
T = .00011    PHI = 150.05   PHIDOT = 17.18   G =-.0219   GDOT = 3.87     PSID = 67.09  PSIDOT =  24.65   PHITOT =  .05
              F23 = 3.7249   F12 =16.2607   PN = .7325    PNPSI = .7325    DPHI2 =  .1591E+06
T = .00012    PHI = 150.06   PHIDOT = 18.77   G =-.0218   GDOT = 4.23     PSID = 67.10  PSIDOT =  26.94   PHITOT =  .06
              F23 = 3.7249   F12 =16.2607   PN = .7323    PNPSI = .7323    DPHI2 =  .1589E+06
T = .00013    PHI = 150.08   PHIDOT = 20.36   G =-.0218   GDOT = 4.59     PSID = 67.12  PSIDOT =  29.24   PHITOT =  .08
              F23 = 3.7287   F12 =16.2614   PN = .7355    PNPSI = .7355    DPHI2 =  .1606E+06
T = .00014    PHI = 150.09   PHIDOT = 21.96   G =-.0217   GDOT = 4.95     PSID = 67.14  PSIDOT =  31.54   PHITOT =  .09
              F23 = 3.7287   F12 =16.2615   PN = .7352    PNPSI = .7352    DPHI2 =  .1603E+06
T = .00015    PHI = 150.10   PHIDOT = 23.57   G =-.0217   GDOT = 5.31     PSID = 67.15  PSIDOT =  33.87   PHITOT =  .10
              F23 = 3.7330   F12 =16.2622   PN = .7388    PNPSI = .7388    DPHI2 =  .1623E+06
T = .00016    PHI = 150.11   PHIDOT = 25.18   G =-.0216   GDOT = 5.67     PSID = 67.17  PSIDOT =  36.21   PHITOT =  .11
              F23 = 3.7331   F12 =16.2624   PN = .7386    PNPSI = .7386    DPHI2 =  .1619E+06
T = .00017    PHI = 150.13   PHIDOT = 26.80   G =-.0216   GDOT = 6.04     PSID = 67.20  PSIDOT =  38.56   PHITOT =  .13
              F23 = 3.7380   F12 =16.2632   PN = .7427    PNPSI = .7427    DPHI2 =  .1642E+06
T = .00018    PHI = 150.15   PHIDOT = 28.44   G =-.0215   GDOT = 6.41     PSID = 67.22  PSIDOT =  40.93   PHITOT =  .15
              F23 = 3.7381   F12 =16.2631   PN = .7424    PNPSI = .7424    DPHI2 =  .1638E+06
T = .00019    PHI = 150.16   PHIDOT = 30.08   G =-.0214   GDOT = 6.78     PSID = 67.24  PSIDOT =  43.33   PHITOT =  .16
              F23 = 3.7436   F12 =16.2644   PN = .7471    PNPSI = .7471    DPHI2 =  .1663E+06
T = .00020    PHI = 150.18   PHIDOT = 31.73   G =-.0214   GDOT = 7.15     PSID = 67.27  PSIDOT =  45.74   PHITOT =  .18
              F23 = 3.7437   F12 =16.2645   PN = .7468    PNPSI = .7468    DPHI2 =  .1658E+06
T = .00021    PHI = 150.20   PHIDOT = 33.40   G =-.0213   GDOT = 7.53     PSID = 67.30  PSIDOT =  48.17   PHITOT =  .20
              F23 = 3.7499   F12 =16.2656   PN = .7519    PNPSI = .7519    DPHI2 =  .1686E+06
T = .00022    PHI = 150.22   PHIDOT = 35.07   G =-.0212   GDOT = 7.91     PSID = 67.32  PSIDOT =  50.62   PHITOT =  .22
              F23 = 3.7500   F12 =16.2658   PN = .7516    PNPSI = .7516    DPHI2 =  .1681E+06
T = .00023    PHI = 150.24   PHIDOT = 36.76   G =-.0211   GDOT = 8.29     PSID = 67.35  PSIDOT =  53.10   PHITOT =  .24
              F23 = 3.7568   F12 =16.2670   PN = .7573    PNPSI = .7573    DPHI2 =  .1712E+06
T = .00024    PHI = 150.26   PHIDOT = 38.46   G =-.0211   GDOT = 8.67     PSID = 67.38  PSIDOT =  55.59   PHITOT =  .26
              F23 = 3.7569   F12 =16.2672   PN = .7569    PNPSI = .7569    DPHI2 =  .1707E+06
T = .00025    PHI = 150.28   PHIDOT = 40.17   G =-.0210   GDOT = 9.06     PSID = 67.42  PSIDOT =  58.12   PHITOT =  .28
              F23 = 3.7644   F12 =16.2685   PN = .7631    PNPSI = .7631    DPHI2 =  .1740E+06
T = .00026    PHI = 150.31   PHIDOT = 41.90   G =-.0209   GDOT = 9.45     PSID = 67.45  PSIDOT =  60.66   PHITOT =  .31
              F23 = 3.7645   F12 =16.2688   PN = .7627    PNPSI = .7627    DPHI2 =  .1734E+06
T = .00027    PHI = 150.33   PHIDOT = 43.64   G =-.0208   GDOT = 9.85     PSID = 67.49  PSIDOT =  63.24   PHITOT =  .33
              F23 = 3.7726   F12 =16.2702   PN = .7695    PNPSI = .7695    DPHI2 =  .1771E+06
T = .00028    PHI = 150.36   PHIDOT = 45.40   G =-.0207   GDOT = 10.24    PSID = 67.52  PSIDOT =  65.84   PHITOT =  .36
              F23 = 3.7727   F12 =16.2705   PN = .7690    PNPSI = .7690    DPHI2 =  .1764E+06
T = .00029    PHI = 150.39   PHIDOT = 47.17   G =-.0206   GDOT = 10.65    PSID = 67.56  PSIDOT =  68.48   PHITOT =  .38
              F23 = 3.7816   F12 =16.2720   PN = .7764    PNPSI = .7764    DPHI2 =  .1804E+06
T = .00030    PHI = 150.41   PHIDOT = 48.96   G =-.0205   GDOT = 11.05    PSID = 67.60  PSIDOT =  71.14   PHITOT =  .41
              F23 = 3.7817   F12 =16.2723   PN = .7759    PNPSI = .7759    DPHI2 =  .1796E+06
T = .00031    PHI = 150.44   PHIDOT = 50.77   G =-.0204   GDOT = 11.46    PSID = 67.64  PSIDOT =  73.85   PHITOT =  .44
              F23 = 3.7912   F12 =16.2740   PN = .7839    PNPSI = .7839    DPHI2 =  .1839E+06
T = .00032    PHI = 150.47   PHIDOT = 52.59   G =-.0202   GDOT = 11.87    PSID = 67.69  PSIDOT =  76.57   PHITOT =  .47
              F23 = 3.7913   F12 =16.2743   PN = .7833    PNPSI = .7833    DPHI2 =  .1831E+06
T = .00033    PHI = 150.50   PHIDOT = 54.43   G =-.0201   GDOT = 12.29    PSID = 67.73  PSIDOT =  79.34   PHITOT =  .50
              F23 = 3.8016   F12 =16.2761   PN = .7919    PNPSI = .7919    DPHI2 =  .1877E+06
T = .00034    PHI = 150.53   PHIDOT = 56.28   G =-.0200   GDOT = 12.71    PSID = 67.78  PSIDOT =  82.14   PHITOT =  .53
              F23 = 3.8017   F12 =16.2765   PN = .7913    PNPSI = .7913    DPHI2 =  .1868E+06
T = .00035    PHI = 150.56   PHIDOT = 58.17   G =-.0199   GDOT = 13.14    PSID = 67.83  PSIDOT =  84.98   PHITOT =  .56
              F23 = 3.8127   F12 =16.2784   PN = .8005    PNPSI = .8005    DPHI2 =  .1917E+06
T = .00036    PHI = 150.60   PHIDOT = 60.06   G =-.0197   GDOT = 13.57    PSID = 67.87  PSIDOT =  87.85   PHITOT =  .60
              F23 = 3.8129   F12 =16.2788   PN = .7999    PNPSI = .7999    DPHI2 =  .1907E+06
T = .00037    PHI = 150.63   PHIDOT = 61.98   G =-.0196   GDOT = 14.01    PSID = 67.93  PSIDOT =  90.77   PHITOT =  .63
              F23 = 3.8247   F12 =16.2808   PN = .8097    PNPSI = .8097    DPHI2 =  .1960E+06
T = .00038    PHI = 150.67   PHIDOT = 63.92   G =-.0195   GDOT = 14.45    PSID = 67.98  PSIDOT =  93.73   PHITOT =  .67
              F23 = 3.8248   F12 =16.2812   PN = .8090    PNPSI = .8090    DPHI2 =  .1949E+06
T = .00039    PHI = 150.71   PHIDOT = 65.88   G =-.0193   GDOT = 14.90    PSID = 68.03  PSIDOT =  96.73   PHITOT =  .71
              F23 = 3.8373   F12 =16.2834   PN = .8195    PNPSI = .8195    DPHI2 =  .2005E+06
T = .00040    PHI = 150.74   PHIDOT = 67.86   G =-.0192   GDOT = 15.35    PSID = 68.09  PSIDOT =  99.77   PHITOT =  .74
              F23 = 3.8375   F12 =16.2839   PN = .8187    PNPSI = .8187    DPHI2 =  .1994E+06
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T = .00041  PHI = 150.78  PHIDOT =  69.87  G =-.0190  GDOT = 15.80  PSID = 68.15  PSIDOT = 102.87  PHITOT =  .78
            F23 = 3.8503  F12 =16.2862  PN = .8299  PNPSI = .8299  DPHI2 = .2052E+06
T = .00042  PHI = 150.82  PHIDOT =  71.89  G =-.0188  GDOT = 16.27  PSID = 68.21  PSIDOT = 106.00  PHITOT =  .82
            F23 = 3.8510  F12 =16.2866  PN = .8291  PNPSI = .8291  DPHI2 = .2041E+06
T = .00043  PHI = 150.87  PHIDOT =  73.95  G =-.0187  GDOT = 16.74  PSID = 68.27  PSIDOT = 109.19  PHITOT =  .87
            F23 = 3.8552  F12 =16.2891  PN = .8410  PNPSI = .8410  DPHI2 = .2103E+06
T = .00044  PHI = 150.91  PHIDOT =  76.02  G =-.0185  GDOT = 17.21  PSID = 68.33  PSIDOT = 112.41  PHITOT =  .91
            F23 = 3.8554  F12 =16.2896  PN = .8401  PNPSI = .8401  DPHI2 = .2090E+06
T = .00045  PHI = 150.95  PHIDOT =  78.13  G =-.0183  GDOT = 17.69  PSID = 68.40  PSIDOT = 115.71  PHITOT =  .95
            F23 = 3.8604  F12 =16.2922  PN = .8527  PNPSI = .8527  DPHI2 = .2156E+06
T = .00046  PHI = 151.00  PHIDOT =  80.26  G =-.0182  GDOT = 18.18  PSID = 68.47  PSIDOT = 119.04  PHITOT = 1.00
            F23 = 3.8806  F12 =16.2927  PN = .8518  PNPSI = .8518  DPHI2 = .2142E+06
T = .00047  PHI = 151.04  PHIDOT =  82.42  G =-.0180  GDOT = 18.67  PSID = 68.53  PSIDOT = 122.44  PHITOT = 1.04
            F23 = 3.8956  F12 =16.2955  PN = .8651  PNPSI = .8651  DPHI2 = .2211E+06
T = .00048  PHI = 151.09  PHIDOT =  84.59  G =-.0178  GDOT = 19.17  PSID = 68.61  PSIDOT = 125.88  PHITOT = 1.09
            F23 = 3.8958  F12 =16.2961  PN = .8641  PNPSI = .8641  DPHI2 = .2197E+06
T = .00049  PHI = 151.14  PHIDOT =  86.81  G =-.0176  GDOT = 19.67  PSID = 68.68  PSIDOT = 129.39  PHITOT = 1.14
            F23 = 3.9136  F12 =16.2990  PN = .8782  PNPSI = .8782  DPHI2 = .2269E+06
T = .00050  PHI = 151.19  PHIDOT =  89.04  G =-.0174  GDOT = 20.19  PSID = 68.75  PSIDOT = 132.95  PHITOT = 1.19
            F23 = 3.9138  F12 =16.2996  PN = .8772  PNPSI = .8772  DPHI2 = .2254E+06
T = .00051  PHI = 151.24  PHIDOT =  91.32  G =-.0172  GDOT = 20.71  PSID = 68.83  PSIDOT = 136.58  PHITOT = 1.24
            F23 = 3.9317  F12 =16.3026  PN = .8921  PNPSI = .8921  DPHI2 = .2330E+06
T = .00052  PHI = 151.30  PHIDOT =  93.61  G =-.0170  GDOT = 21.23  PSID = 68.91  PSIDOT = 140.26  PHITOT = 1.30
            F23 = 3.9319  F12 =16.3033  PN = .8910  PNPSI = .8910  DPHI2 = .2314E+06
T = .00053  PHI = 151.35  PHIDOT =  95.95  G =-.0168  GDOT = 21.77  PSID = 68.99  PSIDOT = 144.03  PHITOT = 1.35
            F23 = 3.9507  F12 =16.3065  PN = .9067  PNPSI = .9067  DPHI2 = .2394E+06
T = .00054  PHI = 151.41  PHIDOT =  98.30  G =-.0165  GDOT = 22.31  PSID = 69.08  PSIDOT = 147.84  PHITOT = 1.41
            F23 = 3.9509  F12 =16.3072  PN = .9056  PNPSI = .9056  DPHI2 = .2376E+06
T = .00055  PHI = 151.46  PHIDOT = 100.70  G =-.0163  GDOT = 22.86  PSID = 69.16  PSIDOT = 151.73  PHITOT = 1.46
            F23 = 3.9708  F12 =16.3106  PN = .9221  PNPSI = .9221  DPHI2 = .2460E+06
T = .00056  PHI = 151.52  PHIDOT = 103.12  G =-.0161  GDOT = 23.41  PSID = 69.25  PSIDOT = 155.68  PHITOT = 1.52
            F23 = 3.9710  F12 =16.3113  PN = .9209  PNPSI = .9209  DPHI2 = .2442E+06
T = .00057  PHI = 151.58  PHIDOT = 105.58  G =-.0158  GDOT = 23.98  PSID = 69.34  PSIDOT = 159.72  PHITOT = 1.58
            F23 = 3.5749  F12 =16.3147  PN = .9395  PNPSI = .9395  DPHI2 = .2536E+06
T = .00058  PHI = 151.64  PHIDOT = 108.07  G =-.0156  GDOT = 24.55  PSID = 69.43  PSIDOT = 163.82  PHITOT = 1.64
            F23 = 3.5751  F12 =16.3155  PN = .9382  PNPSI = .9382  DPHI2 = .2516E+06
T = .00059  PHI = 151.71  PHIDOT = 110.56  G =-.0153  GDOT = 25.13  PSID = 69.53  PSIDOT = 167.94  PHITOT = 1.71
            F23 = 3.5800  F12 =16.3234  PN = .9259  PNPSI = .9259  DPHI2 = .2433E+06
T = .00060  PHI = 151.77  PHIDOT = 113.00  G =-.0151  GDOT = 25.69  PSID = 69.62  PSIDOT = 172.01  PHITOT = 1.77
            F23 = 3.5803  F12 =16.3242  PN = .9246  PNPSI = .9246  DPHI2 = .2413E+06
T = .00061  PHI = 151.84  PHIDOT = 115.39  G =-.0148  GDOT = 26.24  PSID = 69.72  PSIDOT = 176.02  PHITOT = 1.84
            F23 = 3.5854  F12 =16.3325  PN = .9117  PNPSI = .9117  DPHI2 = .2327E+06
T = .00062  PHI = 151.90  PHIDOT = 117.72  G =-.0146  GDOT = 26.78  PSID = 69.83  PSIDOT = 179.98  PHITOT = 1.90
            F23 = 3.5856  F12 =16.3333  PN = .9103  PNPSI = .9103  DPHI2 = .2306E+06
T = .00063  PHI = 151.97  PHIDOT = 120.00  G =-.0143  GDOT = 27.30  PSID = 69.93  PSIDOT = 183.87  PHITOT = 1.97
            F23 = 3.5909  F12 =16.3419  PN = .8970  PNPSI = .8970  DPHI2 = .2218E+06
T = .00064  PHI = 152.04  PHIDOT = 122.23  G =-.0141  GDOT = 27.82  PSID = 70.04  PSIDOT = 187.70  PHITOT = 2.04
            F23 = 3.5912  F12 =16.3428  PN = .8956  PNPSI = .8956  DPHI2 = .2198E+06
T = .00065  PHI = 152.11  PHIDOT = 124.39  G =-.0137  GDOT = 28.32  PSID = 70.15  PSIDOT = 191.47  PHITOT = 2.11
            F23 = 3.5966  F12 =16.3517  PN = .8818  PNPSI = .8818  DPHI2 = .2108E+06
T = .00066  PHI = 152.18  PHIDOT = 126.51  G =-.0135  GDOT = 28.81  PSID = 70.26  PSIDOT = 195.19  PHITOT = 2.18
            F23 = 3.5969  F12 =16.3525  PN = .8803  PNPSI = .8803  DPHI2 = .2088E+06
T = .00067  PHI = 152.26  PHIDOT = 127.94  G =-.0132  GDOT = 29.15  PSID = 70.37  PSIDOT = 197.86  PHITOT = 2.26
            F23 = 3.9623  F12 =16.3768  PN = .7546  PNPSI = .7546  DPHI2 = .1369E+06
T = .00068  PHI = 152.33  PHIDOT = 129.27  G =-.0129  GDOT = 29.46  PSID = 70.48  PSIDOT = 200.38  PHITOT = 2.33
            F23 = 3.9625  F12 =16.3775  PN = .7533  PNPSI = .7533  DPHI2 = .1354E+06
T = .00069  PHI = 152.40  PHIDOT = 130.65  G =-.0126  GDOT = 29.78  PSID = 70.60  PSIDOT = 203.01  PHITOT = 2.40
            F23 = 3.9879  F12 =16.3821  PN = .7736  PNPSI = .7736  DPHI2 = .1462E+06
T = .00070  PHI = 152.48  PHIDOT = 132.07  G =-.0123  GDOT = 30.11  PSID = 70.72  PSIDOT = 205.70  PHITOT = 2.48
            F23 = 3.9882  F12 =16.3828  PN = .7722  PNPSI = .7722  DPHI2 = .1447E+06
T = .00071  PHI = 152.55  PHIDOT = 133.55  G =-.0120  GDOT = 30.46  PSID = 70.83  PSIDOT = 208.50  PHITOT = 2.55
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                F23 = 4.0143   F12 =16.3875   PN =  .7931   PNPSI =  .7931   DPHI2 =   .1557E+06
T =  .00072     PHI = 152.63   PHIDOT = 135.05   G =-.0117   GDOT = 30.81   PSID = 70.95  PSIDOT = 211.37   PHITOT =  2.63
                F23 = 4.0146   F12 =16.3883   PN =  .7917   PNPSI =  .7917   DPHI2 =   .1540E+06
T =  .00073     PHI = 152.71   PHIDOT = 136.63   G =-.0114   GDOT - 31.18   PSID = 71.08  PSIDOT = 214.36   PHITOT =  2.71
                F23 = 4.0414   F12 =16.3930   PN =  .8132   PNPSI =  .8132   DPHI2 =   .1653E+06
T =  .00074     PHI = 152.79   PHIDOT = 138.23   G =-.0110   GDOT = 31.56   PSID = 71.20  PSIDOT = 217.41   PHITOT =  2.79
                F23 = 4.0417   F12 =16.3938   PN =  .8117   PNPSI =  .8117   DPHI2 =   .1636E+06
T =  .00075     PHI = 152.87   PHIDOT = 139.90   G =-.0107   GDOT = 31.95   PSID = 71.33  PSIDOT = 220.58   PHITOT =  2.87
                F23 = 4.0694   F12 =16.3987   PN =  .8339   PNPSI =  .8339   DPHI2 =   .1750E+06
T =  .00076     PHI = 152.95   PHIDOT = 141.60   G =-.0104   GDOT = 32.34   PSID = 71.45  PSIDOT = 223.82   PHITOT =  2.95
                F23 = 4.0697   F12 =16.3995   PN =  .8323   PNPSI =  .8323   DPHI2 =   .1732E+06
T =  .00077     PHI = 153.03   PHIDOT = 143.36   G =-.0101   GDOT = 32.75   PSID = 71.58  PSIDOT = 227.18   PHITOT =  3.03
                F23 = 4.0982   F12 =16.4045   PN =  .8552   PNPSI =  .8552   DPHI2 =   .1850E+06
T =  .00078     PHI = 153.11   PHIDOT = 145.16   G =-.0098   GDOT = 33.18   PSID = 71.71  PSIDOT = 230.62   PHITOT =  3.11
                F23 = 4.0985   F12 =16.4054   PN =  .8536   PNPSI =  .8536   DPHI2 =   .1830E+06
T =  .00079     PHI = 153.20   PHIDOT = 147.02   G =-.0094   GDOT = 33.61   PSID = 71.85  PSIDOT = 234.18   PHITOT =  3.20
                F23 = 4.1280   F12 =16.4105   PN =  .8772   PNPSI =  .8772   DPHI2 =   .1951E+06
T =  .00080     PHI = 153.28   PHIDOT = 148.92   G =-.0091   GDOT = 34.05   PSID = 71.98  PSIDOT = 237.82   PHITOT =  3.28
                F23 = 4.1283   F12 =16.4115   PN =  .8755   PNPSI =  .8755   DPHI2 =   .1931E+06
T =  .00081     PHI = 153.37   PHIDOT = 150.89   G =-.0087   GDOT = 34.51   PSID = 72.12  PSIDOT = 241.59   PHITOT =  3.37
                F23 = 4.1588   F12 =16.4167   PN =  .9000   PNPSI =  .9000   DPHI2 =   .2054E+06
T =  .00082     PHI = 153.45   PHIDOT = 152.88   G =-.0084   GDOT = 34.98   PSID = 72.26  PSIDOT = 245.43   PHITOT =  3.45
                F23 = 4.1591   F12 =16.4177   PN =  .8981   PNPSI =  .8981   DPHI2 =   .2032E+06
T =  .00083     PHI = 153.54   PHIDOT = 154.95   G =-.0080   GDOT = 35.46   PSID = 72.40  PSIDOT = 249.42   PHITOT =  3.54
                F23 = 4.1906   F12 =16.4231   PN =  .9234   PNPSI =  .9234   DPHI2 =   .2159E+06
T =  .00084     PHI = 153.63   PHIDOT = 157.05   G =-.0077   GDOT = 35.95   PSID = 72.54  PSIDOT = 253.48   PHITOT =  3.63
                F23 = 4.1910   F12 =16.4241   PN =  .9215   PNPSI =  .9215   DPHI2 =   .2136E+06
T =  .00085     PHI = 153.72   PHIDOT = 159.22   G =-.0073   GDOT = 36.46   PSID = 72.69  PSIDOT = 257.68   PHITOT =  3.72
                F23 = 3.7848   F12 =16.4289   PN =  .9537   PNPSI =  .9537   DPHI2 =   .2299E+06
T =  .00086     PHI = 153.81   PHIDOT = 161.43   G =-.0070   GDOT = 36.97   PSID = 72.84  PSIDOT = 261.97   PHITOT =  3.81
                F23 = 3.7851   F12 =16.4300   PN =  .9517   PNPSI =  .9517   DPHI2 =   .2275E+06
T =  .00087     PHI = 153.91   PHIDOT = 163.67   G =-.0066   GDOT = 37.49   PSID = 72.99  PSIDOT = 266.33   PHITOT =  3.91
                F23 = 3.7919   F12 =16.4417   PN =  .9331   PNPSI =  .9331   DPHI2 =   .2160E+06
T =  .00088     PHI = 154.00   PHIDOT = 165.84   G =-.0062   GDOT = 38.00   PSID = 73.15  PSIDOT = 270.62   PHITOT =  4.00
                F23 = 3.7923   F12 =16.4428   PN =  .9311   PNPSI =  .9311   DPHI2 =   .2136E+06
T =  .00089     PHI = 154.10   PHIDOT = 167.94   G =-.0058   GDOT = 38.49   PSID = 73.30  PSIDOT = 274.81   PHITOT =  4.10
                F23 = 3.7992   F12 =16.4548   PN =  .9121   PNPSI =  .9121   DPHI2 =   .2020E+06
T =  .00090     PHI = 154.19   PHIDOT = 169.98   G =-.0054   GDOT = 38.97   PSID = 73.46  PSIDOT = 278.94   PHITOT =  4.19
                F23 = 3.7995   F12 =16.4553   PN =  .9100   PNPSI =  .9100   DPHI2 =   .1997E+06
T =  .00091     PHI = 154.29   PHIDOT = 171.93   G =-.0050   GDOT = 39.42   PSID = 73.62  PSIDOT = 282.95   PHITOT =  4.29
                F23 = 4.1694   F12 =16.4867   PN =  .7491   PNPSI =  .7491   DPHI2 =   .1116E+06
T =  .00092     PHI = 154.39   PHIDOT = 173.83   G =-.0046   GDOT = 39.87   PSID = 73.78  PSIDOT = 286.90   PHITOT =  4.39
                F23 = 4.1697   F12 =16.4876   PN =  .7474   PNPSI =  .7474   DPHI2 =   .1097E+06
T =  .00093     PHI = 154.49   PHIDOT = 174.97   G =-.0042   GDOT = 40.14   PSID = 73.95  PSIDOT = 289.61   PHITOT =  4.49
                F23 = 4.2047   F12 =16.4939   PN =  .7744   PNPSI =  .7744   DPHI2 =   .1237E+06
T =  .00094     PHI = 154.59   PHIDOT = 176.15   G =-.0038   GDOT = 40.42   PSID = 74.12  PSIDOT = 292.40   PHITOT =  4.59
                F23 = 4.2050   F12 =16.4948   PN =  .7725   PNPSI =  .7725   DPHI2 =   .1222E+06
T =  .00095     PHI = 154.69   PHIDOT - 177.41   G =-.0034   GDOT = 40.72   PSID = 74.28  PSIDOT = 295.35   PHITOT =  4.69
                F23 = 4.2408   F12 =16.5012   PN =  .8002   PNPSI =  .8002   DPHI2 =   .1364E+06
T =  .00096     PHI = 154.79   PHIDOT = 178.72   G =-.0030   GDOT - 41.02   PSID = 74.45  PSIDOT = 298.39   PHITOT =  4.79
                F23 = 4.2411   F12 =16.5022   PN =  .7982   PNPSI -  .7982   DPHI2 =   .1347E+06
T =  .00097     PHI = 154.90   PHIDOT = 180.11   G =-.0026   GDOT - 41.35   PSID = 74.63  PSIDOT = 301.58   PHITOT =  4.90
                F23 = 4.2778   F12 =16.5086   PN =  .8266   PNPSI -  .8266   DPHI2 =   .1491E+06
T =  .00098     PHI = 155.00   PHIDOT = 181.54   G =-.0022   GDOT = 41.68   PSID = 74.80  PSIDOT = 304.86   PHITOT =  5.00
                F23 = 4.2781   F12 =16.5096   PN =  .8245   PNPSI =  .8245   DPHI2 =   .1473E+06
T =  .00099     PHI = 155.11   PHIDOT = 183.05   G =-.0018   GDOT = 42.04   PSID = 74.98  PSIDOT = 308.30   PHITOT =  5.11
                F23 = 4.3156   F12 =16.5162   PN =  .8536   PNPSI =  .8536   DPHI2 =   .1620E+06
T =  .00100     PHI = 155.21   PHIDOT = 184.61   G =-.0014   GDOT = 42.40   PSID = 75.15  PSIDOT = 311.84   PHITOT =  5.21
                F23 = 4.3160   F12 =16.5172   PN =  .8515   PNPSI =  .8515   DPHI2 =   .1601E+06
T =  .00101     PHI = 155.32   PHIDOT = 186.25   G =-.0009   GDOT = 42.79   PSID = 75.33  PSIDOT = 315.54   PHITOT =  5.32
                F23 = 4.3545   F12 =16.5239   PN =  .8813   PNPSI =  .8813   DPHI2 =   .1750E+06
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T =  .00102   PHI = 155.42   PHIDOT = 187.94   G =-.0005   GDOT = 43.18   PSID =  75.52   PSIDOT =  319.34   PHITOT =   5.42
              F23 = 4.3549   F12 =16.5250   PN =  .8791   PNPSI =  .8791   DPHI2 =  .1729E+06
T =  .00103   PHI = 155.53   PHIDOT = 189.71   G =-.0001   GDOT = 43.59   PSID =  75.70   PSIDOT =  323.30   PHITOT =   5.53
              F23 = 4.3944   F12 =16.5318   PN =  .9097   PNPSI =  .9097   DPHI2 =  .1881E+06
T =  .00104   PHI = 155.64   PHIDOT = 191.53   G = .0004   GDOT = 44.02   PSID =  75.89   PSIDOT =  327.37   PHITOT =   5.64
              F23 = 4.3948   F12 =16.5329   PN =  .9074   PNPSI =  .9074   DPHI2 =  .1859E+06

FREE MOTION

T =  .00104   PHI = 185.64    PHIDOT = 191.53   PSI = 283.74   PSIDOT =  327.37   PHITOT =   5.64
              FF12 = 15.422    FF23 =  3.916
T =  .00104   PHI = 185.67    PHIDOT = 203.82   PSI = 283.79   PSIDOT =  326.37   PHITOT =   5.67
              FF12 = 13.764    FF23 =  3.924
T =  .00104   PHI = 185.70    PHIDOT = 216.22   PSI = 283.84   PSIDOT =  325.36   PHITOT =   5.70
              FF12 = 13.764    FF23 =  3.924
T =  .00105   PHI = 185.73    PHIDOT = 228.66   PSI = 283.88   PSIDOT =  324.36   PHITOT =   5.73
              FF12 = 13.758    FF23 =  3.510
T =  .00105   PHI = 185.77    PHIDOT = 241.17   PSI = 283.93   PSIDOT =  323.35   PHITOT =   5.77
              FF12 = 13.757    FF23 =  3.510
T =  .00105   PHI = 185.80    PHIDOT = 253.60   PSI = 283.97   PSIDOT =  322.35   PHITOT =   5.80
              FF12 = 13.766    FF23 =  3.504
T =  .00105   PHI = 185.84    PHIDOT = 265.99   PSI = 284.02   PSIDOT =  321.34   PHITOT =   5.84
              FF12 = 13.766    FF23 =  3.504
T =  .00106   PHI = 185.88    PHIDOT = 278.29   PSI = 284.07   PSIDOT =  320.34   PHITOT =   5.88
              FF12 = 13.775    FF23 =  3.498
T =  .00106   PHI = 185.92    PHIDOT = 290.55   PSI = 284.11   PSIDOT =  319.34   PHITOT =   5.92
              FF12 = 13.775    FF23 =  3.498
T =  .00106   PHI = 185.96    PHIDOT = 302.72   PSI = 284.16   PSIDOT =  318.33   PHITOT =   5.96
              FF12 = 13.784    FF23 =  3.492
T =  .00106   PHI = 186.00    PHIDOT = 314.83   PSI = 284.20   PSIDOT =  317.33   PHITOT =   6.00
              FF12 = 13.784    FF23 =  3.492
T =  .00107   PHI = 186.05    PHIDOT = 326.85   PSI = 284.25   PSIDOT =  316.32   PHITOT =   6.05
              FF12 = 13.795    FF23 =  3.485
T =  .00107   PHI = 186.10    PHIDOT = 338.81   PSI = 284.29   PSIDOT =  315.32   PHITOT =   6.10
              FF12 = 13.795    FF23 =  3.485
T =  .00107   PHI = 186.15    PHIDOT = 350.67   PSI = 284.34   PSIDOT =  314.31   PHITOT =   6.15
              FF12 = 13.806    FF23 =  3.477
T =  .00107   PHI = 186.20    PHIDOT = 362.46   PSI = 284.38   PSIDOT =  313.31   PHITOT =   6.20
              FF12 = 13.806    FF23 =  3.477
T =  .00108   PHI = 186.25    PHIDOT = 374.15   PSI = 284.43   PSIDOT =  312.30   PHITOT =   6.25
              FF12 = 13.973    FF23 =  3.865
T =  .00108   PHI = 186.31    PHIDOT = 385.77   PSI = 284.47   PSIDOT =  311.30   PHITOT =   6.31
              FF12 = 13.973    FF23 =  3.865
T =  .00108   PHI = 186.36    PHIDOT = 395.60   PSI = 284.52   PSIDOT =  310.30   PHITOT =   6.36
              FF12 = 13.957    FF23 =  3.857
T =  .00108   PHI = 186.42    PHIDOT = 405.48   PSI = 284.56   PSIDOT =  309.29   PHITOT =   6.42
              FF12 = 13.957    FF23 =  3.857
T =  .00109   PHI = 186.48    PHIDOT = 415.46   PSI = 284.61   PSIDOT =  308.29   PHITOT =   6.48
              FF12 = 13.939    FF23 =  3.849
T =  .00109   PHI = 186.54    PHIDOT = 425.50   PSI = 284.65   PSIDOT =  307.28   PHITOT =   6.54
              FF12 = 13.940    FF23 =  3.849
T =  .00109   PHI = 186.60    PHIDOT = 435.63   PSI = 284.69   PSIDOT =  306.28   PHITOT =   6.60
              FF12 = 13.922    FF23 =  3.841
T =  .00109   PHI = 186.66    PHIDOT = 445.83   PSI = 284.74   PSIDOT =  305.27   PHITOT =   6.66
              FF12 = 13.922    FF23 =  3.841
T =  .00110   PHI = 186.73    PHIDOT = 456.12   PSI = 284.78   PSIDOT =  304.27   PHITOT =   6.73
              FF12 = 13.903    FF23 =  3.832
T =  .00110   PHI = 186.79    PHIDOT = 466.48   PSI = 284.83   PSIDOT =  303.27   PHITOT =   6.79
              FF12 = 13.903    FF23 =  3.832
T =  .00110   PHI = 186.86    PHIDOT = 476.94   PSI = 284.87   PSIDOT =  302.26   PHITOT =   6.86
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                 FF12 = 13.884   FF23 =   3.823
T =  .00110      PHI = 186.93    PHIDOT = 487.47   PSI = 284.91   PSIDOT =  301.26   PHITOT =   6.93
                 FF12 = 13.884   FF23 =   3.823
T =  .00111      PHI = 187.00    PHIDOT = 498.11   PSI = 284.96   PSIDOT =  300.25   PHITOT =   7.00
                 FF12 = 13.863   FF23 =   3.813
T =  .00111      PHI = 187.07    PHIDOT = 508.82   PSI = 285.00   PSIDOT =  299.25   PHITOT =   7.07
                 FF12 = 13.864   FF23 =   3.813
T =  .00111      PHI = 187.15    PHIDOT = 519.64   PSI = 285.04   PSIDOT =  298.24   PHITOT =   7.15
                 FF12 = 13.842   FF23 =   3.803
T =  .00111      PHI = 187.22    PHIDOT = 530.53   PSI = 285.08   PSIDOT =  297.24   PHITOT =   7.22
                 FF12 = 13.843   FF23 =   3.803
T =  .00112      PHI = 187.30    PHIDOT = 541.54   PSI = 285.13   PSIDOT =  296.23   PHITOT =   7.30
                 FF12 = 13.821   FF23 =   3.793
T =  .00112      PHI = 187.38    PHIDOT = 552.63   PSI = 285.17   PSIDOT =  295.23   PHITOT =   7.38
                 FF12 = 13.821   FF23 =   3.793
T =  .00112      PHI = 187.46    PHIDOT = 563.83   PSI = 285.21   PSIDOT =  294.23   PHITOT =   7.46
                 FF12 = 13.798   FF23 =   3.782
T =  .00112      PHI = 187.54    PHIDOT = 575.12   PSI = 285.25   PSIDOT =  293.22   PHITOT =   7.54
                 FF12 = 13.798   FF23 =   3.782
T =  .00113      PHI = 187.62    PHIDOT = 586.52   PSI = 285.29   PSIDOT =  292.22   PHITOT =   7.62
                 FF12 = 13.775   FF23 =   3.771
T =  .00113      PHI = 187.71    PHIDOT = 598.01   PSI = 285.34   PSIDOT =  291.21   PHITOT =   7.71
                 FF12 = 13.775   FF23 =   3.771
T =  .00113      PHI = 187.79    PHIDOT = 609.63   PSI = 285.38   PSIDOT =  290.21   PHITOT =   7.79
                 FF12 = 13.751   FF23 =   3.759
T =  .00113      PHI = 187.88    PHIDOT = 621.33   PSI = 285.42   PSIDOT =  289.20   PHITOT =   7.88
                 FF12 = 13.751   FF23 =   3.760
T =  .00114      PHI = 187.97    PHIDOT = 633.15   PSI = 285.46   PSIDOT =  288.20   PHITOT =   7.97
                 FF12 = 13.755   FF23 =   3.354
T =  .00114      PHI = 188.06    PHIDOT = 644.90   PSI = 285.50   PSIDOT =  287.20   PHITOT =   8.06
                 FF12 = 13.756   FF23 =   3.354
T =  .00114      PHI = 188.16    PHIDOT = 656.46   PSI = 285.54   PSIDOT =  286.19   PHITOT =   8.16
                 FF12 = 13.776   FF23 =   3.339
T =  .00114      PHI = 188.25    PHIDOT = 667.89   PSI = 285.58   PSIDOT =  285.19   PHITOT =   8.25
                 FF12 = 13.776   FF23 =   3.340
T =  .00115      PHI = 188.28    PHIDOT = 670.45   PSI = 285.59   PSIDOT =  284.94   PHITOT =   8.28
                 FF12 = 15.530   FF23 =   3.436
T =  .00115      PHI = 188.30    PHIDOT = 672.65   PSI = 285.60   PSIDOT =  284.68   PHITOT =   8.30
                 FF12 = 15.530   FF23 =   3.436
T =  .00115      PHI = 188.32    PHIDOT = 674.76   PSI = 285.61   PSIDOT =  284.43   PHITOT =   8.32
                 FF12 = 15.524   FF23 =   3.441
T =  .00115      PHI = 188.35    PHIDOT = 676.87   PSI = 285.63   PSIDOT =  284.18   PHITOT =   8.35
                 FF12 = 15.525   FF23 =   3.441
T =  .00115      PHI = 188.37    PHIDOT = 679.00   PSI = 285.64   PSIDOT =  283.93   PHITOT =   8.37
                 FF12 = 15.519   FF23 =   3.445
T =  .00115      PHI = 188.40    PHIDOT = 681.14   PSI = 285.65   PSIDOT =  283.68   PHITOT =   8.40
                 FF12 = 15.519   FF23 =   3.445
T =  .00115      PHI = 188.42    PHIDOT = 683.28   PSI = 285.66   PSIDOT =  283.43   PHITOT =   8.42
                 FF12 = 15.513   FF23 =   3.450
T =  .00115      PHI = 188.44    PHIDOT = 685.44   PSI = 285.67   PSIDOT =  283.18   PHITOT =   8.44
                 FF12 = 15.513   FF23 =   3.450
T =  .00115      PHI = 188.47    PHIDOT = 687.61   PSI = 285.68   PSIDOT =  282.93   PHITOT =   8.47
                 FF12 = 15.508   FF23 =   3.455
T =  .00115      PHI = 188.49    PHIDOT = 689.79   PSI = 285.69   PSIDOT =  282.68   PHITOT =   8.49
                 FF12 = 15.508   FF23 =   3.455
T =  .00115      PHI = 188.52    PHIDOT = 691.98   PSI = 285.70   PSIDOT =  282.42   PHITOT =   8.52
                 FF12 = 15.502   FF23 =   3.460
T =  .00115      PHI = 188.54    PHIDOT = 694.17   PSI = 285.71   PSIDOT =  282.17   PHITOT =   8.54
                 FF12 = 15.502   FF23 =   3.460
T =  .00115      PHI = 188.57    PHIDOT = 696.38   PSI = 285.72   PSIDOT =  281.92   PHITOT =   8.57
                 FF12 = 15.496   FF23 =   3.465
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T =  .00115   PHI = 188.59    PHIDOT = 698.60   PSI = 285.73   PSIDOT =  281.67   PHITOT =   8.59
              FF12 = 15.496    FF23 =   3.465
T =  .00115   PHI = 188.62    PHIDOT = 700.84   PSI = 285.74   PSIDOT =  281.42   PHITOT =   8.62
              FF12 = 15.490    FF23 =   3.470
T =  .00115   PHI = 188.64    PHIDOT = 703.08   PSI = 285.75   PSIDOT =  281.17   PHITOT =   8.64
              FF12 = 15.490    FF23 =   3.470
T =  .00116   PHI = 188.67    PHIDOT = 705.33   PSI = 285.76   PSIDOT =  280.92   PHITOT =   8.67
              FF12 = 15.484    FF23 =   3.474
T =  .00116   PHI = 188.69    PHIDOT = 707.59   PSI = 285.77   PSIDOT =  280.67   PHITOT =   8.69
              FF12 = 15.484    FF23 =   3.474
T =  .00116   PHI = 188.72    PHIDOT = 709.87   PSI = 285.78   PSIDOT =  280.42   PHITOT =   8.72
              FF12 = 15.478    FF23 =   3.479
T =  .00116   PHI = 188.75    PHIDOT = 712.15   PSI = 285.79   PSIDOT =  280.16   PHITOT =   8.75
              FF12 = 15.478    FF23 =   3.479
T =  .00116   PHI = 188.77    PHIDOT = 714.44   PSI = 285.80   PSIDOT =  279.91   PHITOT =   8.77
              FF12 = 15.472    FF23 =   3.484
T =  .00116   PHI = 188.80    PHIDOT = 716.75   PSI = 285.81   PSIDOT =  279.66   PHITOT =   8.80
              FF12 = 15.472    FF23 =   3.484
T =  .00116   PHI = 188.82    PHIDOT = 719.07   PSI = 285.82   PSIDOT =  279.41   PHITOT =   8.82
              FF12 = 15.466    FF23 =   3.489
T =  .00116   PHI = 188.85    PHIDOT = 721.40   PSI = 285.83   PSIDOT =  279.16   PHITOT =   8.85
              FF12 = 15.466    FF23 =   3.489
T =  .00116   PHI = 188.87    PHIDOT = 723.74   PSI = 285.84   PSIDOT =  278.91   PHITOT =   8.87
              FF12 = 15.460    FF23 =   3.494
T =  .00116   PHI = 188.90    PHIDOT = 726.08   PSI = 285.85   PSIDOT =  278.66   PHITOT =   8.90
              FF12 = 15.460    FF23 =   3.494
T =  .00116   PHI = 188.93    PHIDOT = 728.45   PSI = 285.86   PSIDOT =  278.41   PHITOT =   8.93
              FF12 = 15.454    FF23 =   3.500
T =  .00116   PHI = 188.95    PHIDOT = 730.82   PSI = 285.87   PSIDOT =  278.16   PHITOT =   8.95
              FF12 = 15.454    FF23 =   3.500
T =  .00116   PHI = 188.98    PHIDOT = 733.20   PSI = 285.88   PSIDOT =  277.90   PHITOT =   8.98
              FF12 = 15.448    FF23 =   3.505
T =  .00116   PHI = 189.00    PHIDOT = 735.60   PSI = 285.89   PSIDOT =  277.65   PHITOT =   9.00
              FF12 = 15.448    FF23 =   3.505
T =  .00116   PHI = 189.03    PHIDOT = 738.01   PSI = 285.90   PSIDOT =  277.40   PHITOT =   9.03
              FF12 = 15.441    FF23 =   3.510
T =  .00116   PHI = 189.06    PHIDOT = 740.42   PSI = 285.91   PSIDOT =  277.15   PHITOT =   9.06
              FF12 = 15.441    FF23 =   3.510
T =  .00117   PHI = 189.08    PHIDOT = 742.85   PSI = 285.92   PSIDOT =  276.90   PHITOT =   9.08
              FF12 = 15.435    FF23 =   3.515
T =  .00117   PHI = 189.11    PHIDOT = 745.29   PSI = 285.93   PSIDOT =  276.65   PHITOT =   9.11
              FF12 = 15.435    FF23 =   3.515
T =  .00117   PHI = 189.14    PHIDOT = 747.75   PSI = 285.94   PSIDOT =  276.40   PHITOT =   9.14
              FF12 = 15.428    FF23 =   3.520
T =  .00117   PHI = 189.16    PHIDOT = 750.21   PSI = 285.95   PSIDOT =  276.15   PHITOT =   9.16
              FF12 = 15.428    FF23 =   3.520
T =  .00117   PHI = 189.19    PHIDOT = 752.69   PSI = 285.96   PSIDOT =  275.90   PHITOT =   9.19
              FF12 = 15.422    FF23 =   3.525
T =  .00117   PHI = 189.22    PHIDOT = 755.18   PSI = 285.97   PSIDOT =  275.64   PHITOT =   9.22
              FF12 = 15.422    FF23 =   3.525
T =  .00117   PHI = 189.25    PHIDOT = 757.68   PSI = 285.98   PSIDOT =  275.39   PHITOT =   9.25
              FF12 = 15.415    FF23 =   3.531
T =  .00117   PHI = 189.27    PHIDOT = 760.19   PSI = 285.99   PSIDOT =  275.14   PHITOT =   9.27
              FF12 = 15.415    FF23 =   3.531
T =  .00117   PHI = 189.30    PHIDOT = 762.71   PSI = 286.00   PSIDOT =  274.89   PHITOT =   9.30
              FF12 = 15.409    FF23 =   3.536
T =  .00117   PHI = 189.33    PHIDOT = 765.25   PSI = 286.01   PSIDOT =  274.64   PHITOT =   9.33
              FF12 = 15.409    FF23 =   3.536
T =  .00117   PHI = 189.35    PHIDOT = 767.79   PSI = 286.02   PSIDOT =  274.39   PHITOT =   9.35
              FF12 = 15.402    FF23 =   3.541
T =  .00117   PHI = 189.38    PHIDOT = 770.35   PSI = 286.02   PSIDOT =  274.14   PHITOT =   9.38
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Computer program SANDA2 (cont)

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              FF12 = 15.402   FF23 =  3.541
T =  .00117   PHI = 189.41    PHIDOT = 772.92   PSI = 286.03   PSIDOT =  273.89   PHITOT =   9.41
              FF12 = 15.395   FF23 =  3.547
T =  .00117   PHI = 189.44    PHIDOT = 775.51   PSI = 286.04   PSIDOT =  273.64   PHITOT =   9.44
              FF12 = 15.395   FF23 =  3.547
T =  .00117   PHI = 189.46    PHIDOT = 778.10   PSI = 286.05   PSIDOT =  273.38   PHITOT =   9.46
              FF12 = 15.388   FF23 =  3.552
T =  .00117   PHI = 189.49    PHIDOT = 780.71   PSI = 286.06   PSIDOT =  273.13   PHITOT =   9.49
              FF12 = 15.388   FF23 =  3.552
T =  .00118   PHI = 189.52    PHIDOT = 783.33   PSI = 286.07   PSIDOT =  272.88   PHITOT =   9.52
              FF12 = 15.381   FF23 =  3.558
T =  .00118   PHI = 189.55    PHIDOT = 785.96   PSI = 286.08   PSIDOT =  272.63   PHITOT =   9.55
              FF12 = 15.381   FF23 =  3.558
T =  .00118   PHI = 189.58    PHIDOT = 788.61   PSI = 286.09   PSIDOT =  272.38   PHITOT =   9.58
              FF12 = 15.374   FF23 =  3.563
T =  .00118   PHI = 189.61    PHIDOT = 791.27   PSI = 286.10   PSIDOT =  272.13   PHITOT =   9.61
              FF12 = 15.374   FF23 =  3.563
T =  .00118   PHI = 189.63    PHIDOT = 793.94   PSI = 286.11   PSIDOT =  271.88   PHITOT =   9.63
              FF12 = 15.367   FF23 =  3.568
T =  .00118   PHI = 189.66    PHIDOT = 796.62   PSI = 286.12   PSIDOT =  271.63   PHITOT =   9.66
              FF12 = 15.367   FF23 =  3.568
T =  .00118   PHI = 189.69    PHIDOT = 799.32   PSI = 286.13   PSIDOT =  271.38   PHITOT =   9.69
              FF12 = 15.360   FF23 =  3.574
T =  .00118   PHI = 189.72    PHIDOT = 802.02   PSI = 286.14   PSIDOT =  271.12   PHITOT =   9.72
              FF12 = 15.360   FF23 =  3.574
T =  .00118   PHI = 189.75    PHIDOT = 804.75   PSI = 286.15   PSIDOT =  270.87   PHITOT =   9.75
              FF12 = 15.353   FF23 =  3.580
T =  .00118   PHI = 189.78    PHIDOT = 807.48   PSI = 286.16   PSIDOT =  270.62   PHITOT =   9.78
              FF12 = 15.353   FF23 =  3.580
T =  .00118   PHI = 189.81    PHIDOT = 810.23   PSI = 286.17   PSIDOT =  270.37   PHITOT =   9.81
              FF12 = 15.345   FF23 =  3.585
T =  .00118   PHI = 189.84    PHIDOT = 812.99   PSI = 286.18   PSIDOT =  270.12   PHITOT =   9.84
              FF12 = 15.346   FF23 =  3.585
T =  .00118   PHI = 189.86    PHIDOT = 815.76   PSI = 286.19   PSIDOT =  269.87   PHITOT =   9.86
              FF12 = 15.332   FF23 =  3.216
T =  .00118   PHI = 189.89    PHIDOT = 818.54   PSI = 286.20   PSIDOT =  269.62   PHITOT =   9.89
              FF12 = 15.332   FF23 =  3.216
T =  .00118   PHI = 189.92    PHIDOT = 821.35   PSI = 286.21   PSIDOT =  269.37   PHITOT =   9.92
              FF12 = 15.340   FF23 =  3.220
T =  .00118   PHI = 189.95    PHIDOT = 824.15   PSI = 286.22   PSIDOT =  269.12   PHITOT =   9.95
              FF12 = 15.340   FF23 =  3.220
T =  .00119   PHI = 190.01    PHIDOT = 829.72   PSI = 286.24   PSIDOT =  268.61   PHITOT =  10.01
              FF12 = 15.357   FF23 =  3.228
T =  .00119   PHI = 190.07    PHIDOT = 835.26   PSI = 286.26   PSIDOT =  268.11   PHITOT =  10.07
              FF12 = 15.357   FF23 =  3.228
T =  .00119   PHI = 190.13    PHIDOT = 840.78   PSI = 286.28   PSIDOT =  267.61   PHITOT =  10.13
              FF12 = 15.374   FF23 =  3.236
T =  .00119   PHI = 190.19    PHIDOT = 846.26   PSI = 286.30   PSIDOT =  267.11   PHITOT =  10.19
              FF12 = 15.374   FF23 =  3.236
T =  .00119   PHI = 190.25    PHIDOT = 851.72   PSI = 286.32   PSIDOT =  266.61   PHITOT =  10.25
              FF12 = 15.391   FF23 =  3.244
T =  .00119   PHI = 190.31    PHIDOT = 857.15   PSI = 286.33   PSIDOT =  266.10   PHITOT =  10.31
              FF12 = 15.391   FF23 =  3.244
T =  .00119   PHI = 190.38    PHIDOT = 862.54   PSI = 286.35   PSIDOT =  265.60   PHITOT =  10.38
              FF12 = 15.408   FF23 =  3.253
T =  .00119   PHI = 190.44    PHIDOT = 867.91   PSI = 286.37   PSIDOT =  265.10   PHITOT =  10.44
              FF12 = 15.409   FF23 =  3.253
T =  .00120   PHI = 190.47    PHIDOT = 870.25   PSI = 286.38   PSIDOT =  264.85   PHITOT =  10.47
              FF12 = 15.559   FF23 =  3.635
T =  .00120   PHI = 190.50    PHIDOT = 872.55   PSI = 286.39   PSIDOT =  264.60   PHITOT =  10.50
              FF12 = 15.560   FF23 =  3.635
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T =  .00120   PHI = 190.53    PHIDOT = 874.86   PSI = 286.40   PSIDOT =  264.35   PHITOT =  10.53
              FF12 = 15.552    FF23 =  3.641
T =  .00120   PHI = 190.56    PHIDOT = 877.18   PSI = 286.41   PSIDOT =  264.09   PHITOT =  10.56
              FF12 = 15.552    FF23 =  3.641
T =  .00120   PHI = 190.59    PHIDOT = 879.51   PSI = 286.42   PSIDOT =  263.84   PHITOT =  10.59
              FF12 = 15.544    FF23 =  3.647
T =  .00120   PHI = 190.63    PHIDOT = 881.86   PSI = 286.43   PSIDOT =  263.59   PHITOT =  10.63
              FF12 = 15 544    FF23 =  3.648
T =  .00120   PHI = 190.66    PHIDOT = 884.22   PSI = 286.44   PSIDOT =  263.34   PHITOT =  10.66
              FF12 = 15.536    FF23 =  3.654
T =  .00120   PHI = 190.69    PHIDOT = 886.60   PSI = 286.45   PSIDOT =  263.09   PHITOT =  10.69
              FF12 = 15.536    FF23 =  3.654
T =  .00120   PHI = 190.72    PHIDOT = 888.99   PSI = 286.46   PSIDOT =  262.84   PHITOT =  10.72
              FF12 = 15.528    FF23 =  3.660
T =  .00120   PHI = 190.75    PHIDOT = 891.40   PSI = 286.47   PSIDOT =  262.59   PHITOT =  10.75
              FF12 = 15.528    FF23 =  3.660
T =  .00120   PHI = 190.78    PHIDOT = 893.82   PSI = 286.48   PSIDOT =  262.34   PHITOT =  10.78
              FF12 = 15.520    FF23 =  3.666
T =  .00120   PHI = 190.82    PHIDOT = 896.25   PSI = 286.49   PSIDOT =  262.09   PHITOT =  10.82
              FF12 = 15.520    FF23 =  3.666
T =  .00120   PHI = 190.85    PHIDOT = 898.70   PSI = 286.50   PSIDOT =  261.83   PHITOT =  10.85
              FF12 = 15.512    FF23 =  3.672
T =  .00120   PHI = 190.88    PHIDOT = 901.16   PSI = 286.50   PSIDOT =  261.58   PHITOT =  10.88
              FF12 = 15.512    FF23 =  3.672
T =  .00120   PHI = 190.91    PHIDOT = 903.64   PSI = 286.51   PSIDOT =  261.33   PHITOT =  10.91
              FF12 = 15.504    FF23 =  3.679
T =  .00120   PHI = 190.95    PHIDOT = 906.13   PSI = 286.52   PSIDOT =  261.08   PHITOT =  10.95
              FF12 = 15.504    FF23 =  3.679
T =  .00121   PHI = 190.98    PHIDOT = 908.63   PSI = 286.53   PSIDOT =  260.83   PHITOT =  10.98
              FF12 = 15.496    FF23 =  3.685
T =  .00121   PHI = 191.01    PHIDOT = 911.15   PSI = 286.54   PSIDOT =  260.58   PHITOT =  11.01
              FF12 = 15.496    FF23 =  3.685
T =  .00121   PHI = 191.04    PHIDOT = 913.69   PSI = 286.55   PSIDOT =  260.33   PHITOT =  11.04
              FF12 = 15.488    FF23 =  3.691
T =  .00121   PHI = 191.08    PHIDOT = 916.23   PSI = 286.56   PSIDOT =  260.08   PHITOT =  11.08
              FF12 = 15.488    FF23 =  3.691
T =  .00121   PHI = 191.11    PHIDOT = 918.80   PSI = 286.57   PSIDOT =  259.83   PHITOT =  11.11
              FF12 = 15.479    FF23 =  3.697
T =  .00121   PHI = 191.14    PHIDOT = 921.38   PSI = 286.58   PSIDOT =  259.57   PHITOT =  11.14
              FF12 = 15.479    FF23 =  3.698
T =  .00121   PHI = 191.17    PHIDOT = 923.97   PSI = 286.59   PSIDOT =  259.32   PHITOT =  11.17
              FF12 = 15.471    FF23 =  3.704
T =  .00121   PHI = 191.21    PHIDOT = 926.58   PSI = 286.60   PSIDOT =  259.07   PHITOT =  11.21
              FF12 = 15.471    FF23 =  3.704
T =  .00121   PHI = 191.24    PHIDOT = 929.20   PSI = 286.61   PSIDOT =  258.82   PHITOT =  11.24
              FF12 = 15.462    FF23 =  3.710
T =  .00121   PHI = 191.27    PHIDOT = 931.84   PSI = 286.62   PSIDOT =  258.57   PHITOT =  11.27
              FF12 = 15.462    FF23 =  3.710
T =  .00121   PHI = 191.31    PHIDOT = 934.50   PSI = 286.63   PSIDOT =  258.32   PHITOT =  11.31
              FF12 = 15.454    FF23 =  3.717
T =  .00121   PHI = 191.34    PHIDOT = 937.16   PSI = 286.63   PSIDOT =  258.07   PHITOT =  11.34
              FF12 = 15.454    FF23 =  3.717
T =  .00121   PHI = 191.37    PHIDOT = 939.85   PSI = 286.64   PSIDOT =  257.82   PHITOT =  11.37
              FF12 = 15.445    FF23 =  3.723
T =  .00121   PHI = 191.41    PHIDOT = 942.55   PSI = 286.65   PSIDOT =  257.57   PHITOT =  11.41
              FF12 = 15.445    FF23 =  3.723
T =  .00121   PHI = 191.44    PHIDOT = 945.26   PSI = 286.66   PSIDOT =  257.31   PHITOT =  11.44
              FF12 = 15.436    FF23 =  3.730
T =  .00121   PHI = 191.48    PHIDOT = 947.99   PSI = 286.67   PSIDOT =  257.06   PHITOT =  11.48
              FF12 = 15.436    FF23 =  3.730
T =  .00122   PHI = 191.51    PHIDOT = 950.74   PSI = 286.68   PSIDOT =  256.81   PHITOT =  11.51
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Computer program SANDA2 (cont)

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                FF12 = 15.427   FF23 =   3.736
T =  .00122     PHI = 191.54    PHIDOT = 953.50   PSI = 286.69   PSIDOT =  256.56   PHITOT =  11.54
                FF12 = 15.427   FF23 =   3.736
T =  .00122     PHI = 191.58    PHIDOT = 956.28   PSI = 286.70   PSIDOT =  256.31   PHITOT =  11.58
                FF12 = 15.418   FF23 =   3.743
T =  .00122     PHI = 191.61    PHIDOT = 959.07   PSI = 286.71   PSIDOT =  256.06   PHITOT =  11.61
                FF12 = 15.419   FF23 =   3.743
T =  .00122     PHI = 191.65    PHIDOT = 961.88   PSI = 286.72   PSIDOT =  255.81   PHITOT =  11.65
                FF12 = 15.409   FF23 =   3.749
T =  .00122     PHI = 191.68    PHIDOT = 964.70   PSI = 286.73   PSIDOT =  255.56   PHITOT =  11.68
                FF12 = 15.409   FF23 =   3.750
T =  .00122     PHI = 191.72    PHIDOT = 967.54   PSI = 286.74   PSIDOT =  255.31   PHITOT =  11.72
                FF12 = 15.400   FF23 =   3.756
T =  .00122     PHI = 191.75    PHIDOT = 970.40   PSI = 286.74   PSIDOT =  255.05   PHITOT =  11.75
                FF12 = 15.400   FF23 =   3.756
T =  .00122     PHI = 191.79    PHIDOT = 973.27   PSI = 286.75   PSIDOT =  254.80   PHITOT =  11.79
                FF12 = 15.391   FF23 =   3.763
T =  .00122     PHI = 191.82    PHIDOT = 976.16   PSI = 286.76   PSIDOT =  254.55   PHITOT =  11.82
                FF12 = 15.391   FF23 =   3.763
T =  .00122     PHI = 191.86    PHIDOT = 979.07   PSI = 286.77   PSIDOT =  254.30   PHITOT =  11.86
                FF12 = 15.382   FF23 =   3.770
T =  .00122     PHI = 191.89    PHIDOT = 981.98   PSI = 286.78   PSIDOT =  254.05   PHITOT =  11.89
                FF12 = 15.382   FF23 =   3.770
T =  .00122     PHI = 191.93    PHIDOT = 984.92   PSI = 286.79   PSIDOT =  253.80   PHITOT =  11.93
                FF12 = 15.372   FF23 =   3.776
T =  .00122     PHI = 191.96    PHIDOT = 987.87   PSI = 286.80   PSIDOT =  253.55   PHITOT =  11.96
                FF12 = 15.372   FF23 =   3.776
T =  .00122     PHI = 192.00    PHIDOT = 990.85   PSI = 286.81   PSIDOT =  253.30   PHITOT =  12.00
                FF12 = 15.368   FF23 =   3.387
T =  .00122     PHI = 192.03    PHIDOT = 993.84   PSI = 286.82   PSIDOT =  253.05   PHITOT =  12.03
                FF12 = 15.368   FF23 =   3.387
T =  .00123     PHI = 192.07    PHIDOT = 996.81   PSI = 286.83   PSIDOT =  252.79   PHITOT =  12.07
                FF12 = 15.378   FF23 =   3.392
T =  .00123     PHI = 192.10    PHIDOT = 999.78   PSI = 286.84   PSIDOT =  252.54   PHITOT =  12.10
                FF12 = 15.378   FF23 =   3.392
T =  .00123     PHI = 192.14    PHIDOT =1002.74   PSI = 286.84   PSIDOT =  252.29   PHITOT =  12.14
                FF12 = 15.389   FF23 =   3.397
T =  .00123     PHI = 192.18    PHIDOT =1005.69   PSI = 286.85   PSIDOT =  252.04   PHITOT =  12.18
                FF12 = 15.389   FF23 =   3.397
T =  .00123     PHI = 192.21    PHIDOT =1008.63   PSI = 286.86   PSIDOT =  251.79   PHITOT =  12.21
                FF12 = 15.399   FF23 =   3.402
T =  .00123     PHI = 192.25    PHIDOT =1011.56   PSI = 286.87   PSIDOT =  251.54   PHITOT =  12.25
                FF12 = 15.400   FF23 =   3.402
T =  .00123     PHI = 192.28    PHIDOT =1014.48   PSI = 286.88   PSIDOT =  251.29   PHITOT =  12.28
                FF12 = 15.410   FF23 =   3.407
T =  .00123     PHI = 192.32    PHIDOT =1017.39   PSI = 286.89   PSIDOT =  251.04   PHITOT =  12.32
                FF12 = 15.410   FF23 =   3.407
T =  .00123     PHI = 192.36    PHIDOT =1020.30   PSI = 286.90   PSIDOT =  250.79   PHITOT =  12.36
                FF12 = 15.421   FF23 =   3.412
T =  .00123     PHI = 192.39    PHIDOT =1023.19   PSI = 286.91   PSIDOT =  250.54   PHITOT =  12.39
                FF12 = 15.421   FF23 =   3.412
T =  .00123     PHI = 192.43    PHIDOT =1026.07   PSI = 286.92   PSIDOT =  250.28   PHITOT =  12.43
                FF12 = 15.432   FF23 =   3.418
T =  .00123     PHI = 192.47    PHIDOT =1028.95   PSI = 286.93   PSIDOT =  250.03   PHITOT =  12.47
                FF12 = 15.432   FF23 =   3.418
T =  .00123     PHI = 192.50    PHIDOT =1031.81   PSI = 286.93   PSIDOT =  249.78   PHITOT =  12.50
                FF12 = 15.443   FF23 =   3.423
T =  .00123     PHI = 192.54    PHIDOT =1034.66   PSI = 286.94   PSIDOT =  249.53   PHITOT =  12.54
                FF12 = 15.443   FF23 =   3.423
T =  .00123     PHI = 192.56    PHIDOT =1035.91   PSI = 286.95   PSIDOT =  249.41   PHITOT =  12.56
                FF12 = 15.607   FF23 =   3.821
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T =  .00123   PHI = 192.58    PHIDOT =1037.13   PSI = 286.95   PSIDOT =  249.28   PHITOT =  12.58
              FF12 = 15.607    FF23 =   3.821
T =  .00123   PHI = 192.60    PHIDOT =1038.35   PSI = 286.96   PSIDOT =  249.15   PHITOT =  12.60
              FF12 = 15.602    FF23 =   3.824
T =  .00123   PHI = 192.62    PHIDOT =1039.57   PSI = 286.96   PSIDOT =  249.03   PHITOT =  12.62
              FF12 = 15.602    FF23 =   3.824
T =  .00124   PHI = 192.65    PHIDOT =1042.03   PSI = 286.97   PSIDOT =  248.78   PHITOT =  12.65
              FF12 = 15.593    FF23 =   3.831
T =  .00124   PHI = 192.69    PHIDOT =1044.51   PSI = 286.98   PSIDOT =  248.53   PHITOT =  12.69
              FF12 = 15.593    FF23 =   3.831
T =  .00124   PHI = 192.73    PHIDOT =1047.01   PSI = 286.99   PSIDOT =  248.28   PHITOT =  12.73
              FF12 = 15.583    FF23 =   3.839
T =  .00124   PHI = 192.76    PHIDOT =1049.52   PSI = 287.00   PSIDOT =  248.02   PHITOT =  12.76
              FF12 = 15.583    FF23 =   3.839
T =  .00124   PHI = 192.80    PHIDOT =1052.05   PSI = 287.01   PSIDOT =  247.77   PHITOT =  12.80
              FF12 = 15.573    FF23 =   3.846
T =  .00124   PHI = 192.84    PHIDOT =1054.60   PSI = 287.01   PSIDOT =  247.52   PHITOT =  12.84
              FF12 = 15.573    FF23 =   3.846
T =  .00124   PHI = 192.88    PHIDOT =1057.17   PSI = 287.02   PSIDOT =  247.27   PHITOT =  12.88
              FF12 = 15.563    FF23 =   3.853
T =  .00124   PHI = 192.92    PHIDOT =1059.75   PSI = 287.03   PSIDOT =  247.02   PHITOT =  12.92
              FF12 = 15.563    FF23 =   3.853
T    .00124   PHI = 192.95    PHIDOT =1062.35   PSI = 287.04   PSIDOT =  246.77   PHITOT =  12.95
              FF12 = 15.553    FF23 =   3.860
T =  .00124   PHI = 192.99    PHIDOT =1064.96   PSI = 287.05   PSIDOT =  246.52   PHITOT =  12.99
              FF12 = 15.553    FF23 =   3.860
T =  .00124   PHI = 193.03    PHIDOT =1067.60   PSI = 287.06   PSIDOT =  246.27   PHITOT =  13.03
              FF12 = 15.543    FF23 =   3.868
T =  .00124   PHI = 193.07    PHIDOT =1070.25   PSI = 287.07   PSIDOT =  246.02   PHITOT =  13.07
              FF12 = 15.543    FF23 =   3.868
T =  .00124   PHI = 193.11    PHIDOT =1072.93   PSI = 287.08   PSIDOT =  245.76   PHITOT =  13.11
              FF12 = 15.532    FF23 =   3.875
T =  .00124   PHI = 193.15    PHIDOT =1075.61   PSI = 287.09   PSIDOT =  245.51   PHITOT =  13.15
              FF12 = 15.533    FF23 =   3.875
T =  .00124   PHI = 193.18    PHIDOT =1078.32   PSI = 287.09   PSIDOT =  245.26   PHITOT =  13.18
              FF12 = 15.522    FF23 =   3.883
T =  .00124   PHI = 193.22    PHIDOT =1081.04   PSI = 287.10   PSIDOT =  245.01   PHITOT =  13.22
              FF12 = 15.522    FF23 =   3.883
T =  .00125   PHI = 193.26    PHIDOT =1083.79   PSI = 287.11   PSIDOT =  244.76   PHITOT =  13.26
              FF12 = 15.512    FF23 =   3.890
T =  .00125   PHI = 193.30    PHIDOT =1086.55   PSI = 287.12   PSIDOT =  244.51   PHITOT =  13.30
              FF12 = 15.512    FF23 =   3.890
T =  .00125   PHI = 193.34    PHIDOT =1089.33   PSI = 287.13   PSIDOT =  244.26   PHITOT =  13.34
              FF12 = 15.501    FF23 =   3.897
T =  .00125   PHI = 193.38    PHIDOT =1092.13   PSI = 287.14   PSIDOT =  244.01   PHITOT =  13.38
              FF12 = 15.501    FF23 =   3.897
T =  .00125   PHI = 193.42    PHIDOT =1094.94   PSI = 287.15   PSIDOT =  243.76   PHITOT =  13.42
              FF12 = 15.490    FF23 =   3.905
T =  .00125   PHI = 193.46    PHIDOT =1097.78   PSI = 287.16   PSIDOT =  243.50   PHITOT =  13.46
              FF12 = 15.491    FF23 =   3.905
T =  .00125   PHI = 193.50    PHIDOT =1100.63   PSI = 287.16   PSIDOT =  243.25   PHITOT =  13.50
              FF12 = 15.480    FF23 =   3.912
T =  .00125   PHI = 193.54    PHIDOT =1103.50   PSI = 287.17   PSIDOT =  243.00   PHITOT =  13.54
              FF12 = 15.480    FF23 =   3.912
T =  .00125   PHI = 193.58    PHIDOT =1106.39   PSI = 287.18   PSIDOT =  242.75   PHITOT =  13.58
              FF12 = 15.469    FF23 =   3.920
T =  .00125   PHI = 193.61    PHIDOT =1109.30   PSI = 287.19   PSIDOT =  242.50   PHITOT =  13.61
              FF12 = 15.469    FF23 =   3.920
T =  .00125   PHI = 193.65    PHIDOT =1112.23   PSI = 287.20   PSIDOT =  242.25   PHITOT =  13.65
              FF12 = 15.458    FF23 =   3.928
T =  .00125   PHI = 193.69    PHIDOT =1115.18   PSI = 287.21   PSIDOT =  242.00   PHITOT =  13.69
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                FF12 = 15.458   FF23 =  3.928
T =   .00125    PHI = 193.73    PHIDOT =1118.14   PSI = 287.22   PSIDOT =  241.75   PHITOT =  13.73
                FF12 = 15.447   FF23 =  3.935
T =   .00125    PHI = 193.77    PHIDOT =1121.13   PSI = 287.23   PSIDOT =  241.50   PHITOT =  13.77
                FF12 = 15.447   FF23 =  3.935
T =   .00125    PHI = 193.81    PHIDOT =1124.14   PSI = 287.23   PSIDOT =  241.24   PHITOT =  13.81
                FF12 = 13.820   FF23 =  3.937
T =   .00125    PHI = 193.85    PHIDOT =1127.16   PSI = 287.24   PSIDOT =  240.99   PHITOT =  13.85
                FF12 = 13.820   FF23 =  3.937
T =   .00126    PHI = 193.90    PHIDOT =1130.19   PSI = 287.25   PSIDOT =  240.74   PHITOT =  13.90
                FF12 = 13.808   FF23 =  3.932
T =   .00126    PHI = 193.94    PHIDOT =1133.24   PSI = 287.26   PSIDOT =  240.49   PHITOT =  13.94
                FF12 = 13.809   FF23 =  3.932
T =   .00126    PHI = 193.98    PHIDOT =1136.30   PSI = 287.27   PSIDOT =  240.24   PHITOT =  13.98
                FF12 = 13.797   FF23 =  3.926
T =   .00126    PHI = 194.02    PHIDOT =1139.37   PSI = 287.28   PSIDOT =  239.99   PHITOT =  14.02
                FF12 = 13.797   FF23 =  3.926
T =   .00126    PHI = 194.06    PHIDOT =1142.46   PSI = 287.29   PSIDOT =  239.74   PHITOT =  14.06
                FF12 = 13.785   FF23 =  3.921
T =   .00126    PHI = 194.10    PHIDOT =1145.56   PSI = 287.29   PSIDOT =  239.49   PHITOT =  14.10
                FF12 = 13.785   FF23 =  3.921
T =   .00126    PHI = 194.14    PHIDOT =1148.68   PSI = 287.30   PSIDOT =  239.24   PHITOT =  14.14
                FF12 = 13.784   FF23 =  3.505
T =   .00126    PHI = 194.18    PHIDOT =1151.79   PSI = 287.31   PSIDOT =  238.98   PHITOT =  14.18
                FF12 = 13.784   FF23 =  3.505
T =   .00126    PHI = 194.26    PHIDOT =1157.95   PSI = 287.33   PSIDOT =  238.48   PHITOT =  14.26
                FF12 = 13.803   FF23 =  3.493
T =   .00126    PHI = 194.35    PHIDOT =1164.06   PSI = 287.35   PSIDOT =  237.98   PHITOT =  14.35
                FF12 = 13.804   FF23 =  3.493
T =   .00126    PHI = 194.43    PHIDOT =1170.08   PSI = 287.36   PSIDOT =  237.48   PHITOT =  14.43
                FF12 = 13.823   FF23 =  3.480
T =   .00126    PHI = 194.51    PHIDOT =1176.05   PSI = 287.38   PSIDOT =  236.98   PHITOT =  14.51
                FF12 = 13.823   FF23 =  3.480
T =   .00127    PHI = 194.60    PHIDOT =1181.92   PSI = 287.40   PSIDOT =  236.47   PHITOT =  14.60
                FF12 = 13.843   FF23 =  3.468
T =   .00127    PHI = 194.68    PHIDOT =1187.75   PSI = 287.41   PSIDOT =  235.97   PHITOT =  14.68
                FF12 = 13.843   FF23 =  3.468
T =   .00127    PHI = 194.77    PHIDOT =1192.81   PSI = 287.43   PSIDOT =  235.47   PHITOT =  14.77
                FF12 = 13.974   FF23 =  3.851
T =   .00127    PHI = 194.86    PHIDOT =1197.77   PSI = 287.45   PSIDOT =  234.97   PHITOT =  14.86
                FF12 = 13.975   FF23 =  3.851
T =   .00127    PHI = 194.94    PHIDOT =1202.79   PSI = 287.46   PSIDOT =  234.46   PHITOT =  14.94
                FF12 = 13.950   FF23 =  3.839
T =   .00127    PHI = 195.03    PHIDOT =1207.86   PSI = 287.48   PSIDOT =  233.96   PHITOT =  15.03
                FF12 = 13.950   FF23 =  3.840
T =   .00127    PHI = 195.11    PHIDOT =1213.00   PSI = 287.50   PSIDOT =  233.46   PHITOT =  15.11
                FF12 = 13.925   FF23 =  3.828
T =   .00127    PHI = 195.20    PHIDOT =1218.17   PSI = 287.51   PSIDOT =  232.96   PHITOT =  15.20
                FF12 = 13.925   FF23 =  3.828
T =   .00128    PHI = 195.29    PHIDOT =1223.42   PSI = 287.53   PSIDOT =  232.46   PHITOT =  15.29
                FF12 = 13.900   FF23 =  3.816
T =   .00128    PHI = 195.38    PHIDOT =1228.71   PSI = 287.55   PSIDOT =  231.95   PHITOT =  15.38
                FF12 = 13.901   FF23 =  3.816
T =   .00128    PHI = 195.46    PHIDOT =1234.07   PSI = 287.56   PSIDOT =  231.45   PHITOT =  15.46
                FF12 = 13.876   FF23 =  3.804
T =   .00128    PHI = 195.55    PHIDOT =1239.47   PSI = 287.58   PSIDOT =  230.95   PHITOT =  15.55
                FF12 = 13.876   FF23 =  3.804
T =   .00128    PHI = 195.64    PHIDOT =1244.94   PSI = 287.60   PSIDOT =  230.45   PHITOT =  15.64
                FF12 = 13.851   FF23 =  3.792
T =   .00128    PHI = 195.73    PHIDOT =1250.46   PSI = 287.61   PSIDOT =  229.95   PHITOT =  15.73
                FF12 = 13.851   FF23 =  3.792
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T =  .00128   PHI = 195.82    PHIDOT =1256.04   PSI = 287.63   PSIDOT =  229.44   PHITOT =  15.82
              FF12 = 13.826    FF23 =  3.780
T =  .00128   PHI = 195.91    PHIDOT =1261.66   PSI = 287.65   PSIDOT =  228.94   PHITOT =  15.91
              FF12 = 13.826    FF23 =  3.780
T =  .00129   PHI = 196.00    PHIDOT =1267.36   PSI = 287.66   PSIDOT =  228.44   PHITOT =  16.00
              FF12 = 13.801    FF23 =  3.768
T =  .00129   PHI = 196.09    PHIDOT =1273.10   PSI = 287.68   PSIDOT =  227.94   PHITOT =  16.09
              FF12 = 13.801    FF23 =  3.768
T =  .00129   PHI = 196.18    PHIDOT =1278.90   PSI = 287.70   PSIDOT =  227.43   PHITOT =  16.18
              FF12 = 13.776    FF23 =  3.756
T =  .00129   PHI = 196.28    PHIDOT =1284.75   PSI = 287.71   PSIDOT =  226.93   PHITOT =  16.28
              FF12 = 13.776    FF23 =  3.756
T =  .00129   PHI = 196.37    PHIDOT =1290.66   PSI = 287.73   PSIDOT =  226.43   PHITOT =  16.37
              FF12 = 13.784    FF23 =  3.350
T =  .00129   PHI = 196.46    PHIDOT =1296.51   PSI = 287.74   PSIDOT =  225.93   PHITOT =  16.46
              FF12 = 13.784    FF23 =  3.350
T =  .00129   PHI = 196.55    PHIDOT =1302.27   PSI = 287.76   PSIDOT =  225.43   PHITOT =  16.55
              FF12 = 15.381    FF23 =  3.088
T =  .00129   PHI = 196.65    PHIDOT =1307.88   PSI = 287.78   PSIDOT =  224.92   PHITOT =  16.65
              FF12 = 15.382    FF23 =  3.088
T =  .00130   PHI = 196.74    PHIDOT =1312.98   PSI = 287.79   PSIDOT =  224.42   PHITOT =  16.74
              FF12 = 15.407    FF23 =  3.101
T =  .00130   PHI = 196.84    PHIDOT =1318.05   PSI = 287.81   PSIDOT =  223.92   PHITOT =  16.84
              FF12 = 15.407    FF23 =  3.101
T =  .00130   PHI = 196.88    PHIDOT =1320.27   PSI = 287.82   PSIDOT =  223.67   PHITOT =  16.88
              FF12 = 15.546    FF23 =  3.471
T =  .00130   PHI = 196.93    PHIDOT =1322.45   PSI = 287.82   PSIDOT =  223.42   PHITOT =  16.93
              FF12 = 15.546    FF23 =  3.472
T =  .00130   PHI = 196.98    PHIDOT =1324.65   PSI = 287.83   PSIDOT =  223.17   PHITOT =  16.98
              FF12 = 15.535    FF23 =  3.481
T =  .00130   PHI = 197.02    PHIDOT =1326.86   PSI = 287.84   PSIDOT =  222.91   PHITOT =  17.02
              FF12 = 15.535    FF23 =  3.481
T =  .00130   PHI = 197.07    PHIDOT =1329.10   PSI = 287.85   PSIDOT =  222.66   PHITOT =  17.07
              FF12 = 15.523    FF23 =  3.490
T =  .00130   PHI = 197.12    PHIDOT =1331.35   PSI = 287.86   PSIDOT =  222.41   PHITOT =  17.12
              FF12 = 15.524    FF23 =  3.490
T =  .00130   PHI = 197.17    PHIDOT =1333.63   PSI = 287.86   PSIDOT =  222.16   PHITOT =  17.17
              FF12 = 15.512    FF23 =  3.499
T =  .00130   PHI = 197.22    PHIDOT =1335.93   PSI = 287.87   PSIDOT =  221.91   PHITOT =  17.22
              FF12 = 15.512    FF23 =  3.499
T =  .00130   PHI = 197.26    PHIDOT =1338.25   PSI = 287.88   PSIDOT =  221.66   PHITOT =  17.26
              FF12 = 15.501    FF23 =  3.509
T =  .00130   PHI = 197.31    PHIDOT =1340.58   PSI = 287.89   PSIDOT =  221.41   PHITOT =  17.31
              FF12 = 15.501    FF23 =  3.509
T =  .00130   PHI = 197.36    PHIDOT =1342.94   PSI = 287.90   PSIDOT =  221.16   PHITOT =  17.36
              FF12 = 15.489    FF23 =  3.518
T =  .00130   PHI = 197.41    PHIDOT =1345.32   PSI = 287.90   PSIDOT =  220.91   PHITOT =  17.41
              FF12 = 15.490    FF23 =  3.518
VP= -13.809   VS= 148.198

   IMPACT

              PHI= 197.408   PHIDOT=  60.802   PSI= 287.904   PSIDOT=-107.144   PHITOT =  17.408
VP=   6.699   VS=   6.698

   COUPLED MOTION
T =  .00130   PHI = 197.41    PHIDOT =  60.80   G =-.0087   GDOT = 15.31   PSID = 287.85   PSIDOT = -107.22   PHITOT =  17.41
              F23 = 3.8780    F12 =16.3940   PN =  .7646   PNPSI =  .7646   DPHI2 =   .1525E+06
T =  .00131   PHI = 197.44    PHIDOT =  62.33   G =-.0085   GDOT = 15.72   PSID = 287.79   PSIDOT = -110.22   PHITOT =  17.44
              F23 = 3.8903    F12 =16.3967   PN =  .7743   PNPSI =  .7743   DPHI2 =   .1551E+06
T =  .00132   PHI = 197.48    PHIDOT =  63.86   G =-.0083   GDOT = 16.13   PSID = 287.72   PSIDOT = -113.23   PHITOT =  17.48
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                F23 = 3.8905   F12 =16.3974   PN = .7739   PNPSI = .7739   DPHI2 = .1529E+06
T = .00133      PHI = 197.52   PHIDOT = 65.39   G =-.0082   GDOT = 16.55   PSID = 287.66   PSIDOT = -116.28   PHITOT = 17.52
                F23 = 3.9035   F12 =16.4003   PN = .7842   PNPSI = .7842   DPHI2 = .1556E+06
T = .00134      PHI = 197.55   PHIDOT = 66.92   G =-.0080   GDOT = 16.97   PSID = 287.59   PSIDOT = -119.35   PHITOT = 17.55
                F23 = 3.9037   F12 =16.4010   PN = .7838   PNPSI = .7838   DPHI2 = .1532E+06
T = .00135      PHI = 197.59   PHIDOT = 68.45   G =-.0078   GDOT = 17.39   PSID = 287.52   PSIDOT = -122.46   PHITOT = 17.59
                F23 = 3.9173   F12 =16.4041   PN = .7946   PNPSI = .7946   DPHI2 = .1560E+06
T = .00136      PHI = 197.63   PHIDOT = 69.99   G =-.0077   GDOT = 17.81   PSID = 287.45   PSIDOT = -125.59   PHITOT = 17.63
                F23 = 3.9176   F12 =16.4048   PN = .7941   PNPSI = .7941   DPHI2 = .1534E+06
T = .00137      PHI = 197.67   PHIDOT = 71.52   G =-.0075   GDOT = 18.24   PSID = 287.38   PSIDOT = -128.76   PHITOT = 17.67
                F23 = 3.9319   F12 =16.4080   PN = .8055   PNPSI = .8055   DPHI2 = .1562E+06
T = .00138      PHI = 197.71   PHIDOT = 73.05   G =-.0073   GDOT = 18.67   PSID = 287.30   PSIDOT = -131.94   PHITOT = 17.71
                F23 = 3.9322   F12 =16.4089   PN = .8050   PNPSI = .8050   DPHI2 = .1535E+06
T = .00139      PHI = 197.76   PHIDOT = 74.59   G =-.0071   GDOT = 19.10   PSID = 287.23   PSIDOT = -135.17   PHITOT = 17.76
                F23 = 3.9471   F12 =16.4122   PN = .8169   PNPSI = .8169   DPHI2 = .1564E+06
T = .00140      PHI = 197.80   PHIDOT = 76.13   G =-.0069   GDOT = 19.53   PSID = 287.15   PSIDOT = -138.42   PHITOT = 17.80
                F23 = 3.9474   F12 =16.4131   PN = .8163   PNPSI = .8163   DPHI2 = .1535E+06
T = .00141      PHI = 197.84   PHIDOT = 77.66   G =-.0067   GDOT = 19.97   PSID = 287.07   PSIDOT = -141.72   PHITOT = 17.84
                F23 = 3.9630   F12 =16.4166   PN = .8288   PNPSI = .8288   DPHI2 = .1564E+06
T = .00142      PHI = 197.89   PHIDOT = 79.20   G =-.0065   GDOT = 20.41   PSID = 286.99   PSIDOT = -145.03   PHITOT = 17.89
                F23 = 3.9634   F12 =16.4176   PN = .8282   PNPSI = .8282   DPHI2 = .1534E+06
T = .00143      PHI = 197.93   PHIDOT = 80.73   G =-.0063   GDOT = 20.85   PSID = 286.90   PSIDOT = -148.39   PHITOT = 17.93
                F23 = 3.9797   F12 =16.4212   PN = .8412   PNPSI = .8412   DPHI2 = .1563E+06
T = .00144      PHI = 197.98   PHIDOT = 82.26   G =-.0061   GDOT = 21.30   PSID = 286.82   PSIDOT = -151.77   PHITOT = 17.98
                F23 = 3.9801   F12 =16.4222   PN = .8406   PNPSI = .8406   DPHI2 = .1532E+06
T = .00145      PHI = 198.03   PHIDOT = 83.80   G =-.0059   GDOT = 21.75   PSID = 286.73   PSIDOT = -155.19   PHITOT = 18.03
                F23 = 3.9971   F12 =16.4261   PN = .8541   PNPSI = .8541   DPHI2 = .1561E+06
T = .00146      PHI = 198.08   PHIDOT = 85.32   G =-.0057   GDOT = 22.20   PSID = 286.64   PSIDOT = -158.64   PHITOT = 18.08
                F23 = 3.9975   F12 =16.4271   PN = .8535   PNPSI = .8535   DPHI2 = .1528E+06
T = .00147      PHI = 198.13   PHIDOT = 86.85   G =-.0054   GDOT = 22.65   PSID = 286.55   PSIDOT = -162.13   PHITOT = 18.13
                F23 = 4.0152   F12 =16.4311   PN = .8676   PNPSI = .8676   DPHI2 = .1557E+06
T = .00148      PHI = 198.18   PHIDOT = 88.37   G =-.0052   GDOT = 23.11   PSID = 286.45   PSIDOT = -165.65   PHITOT = 18.18
                F23 = 4.0156   F12 =16.4322   PN = .8669   PNPSI = .8669   DPHI2 = .1522E+06
T = .00149      PHI = 198.23   PHIDOT = 89.90   G =-.0050   GDOT = 23.57   PSID = 286.36   PSIDOT = -169.21   PHITOT = 18.23
                F23 = 4.0340   F12 =16.4364   PN = .8816   PNPSI = .8816   DPHI2 = .1551E+06
T = .00150      PHI = 198.28   PHIDOT = 91.41   G =-.0047   GDOT = 24.03   PSID = 286.26   PSIDOT = -172.80   PHITOT = 18.28
                F23 = 4.0344   F12 =16.4375   PN = .8809   PNPSI = .8809   DPHI2 = .1514E+06
T = .00151      PHI = 198.33   PHIDOT = 92.92   G =-.0045   GDOT = 24.49   PSID = 286.16   PSIDOT = -176.43   PHITOT = 18.33
                F23 = 3.6300   F12 =16.4418   PN = .8970   PNPSI = .8970   DPHI2 = .1546E+06
T = .00152      PHI = 198.39   PHIDOT = 94.43   G =-.0043   GDOT = 24.96   PSID = 286.06   PSIDOT = -180.09   PHITOT = 18.39
                F23 = 3.6304   F12 =16.4430   PN = .8962   PNPSI = .8962   DPHI2 = .1508E+06
T = .00153      PHI = 198.44   PHIDOT = 95.91   G =-.0040   GDOT = 25.43   PSID = 285.95   PSIDOT = -183.74   PHITOT = 18.44
                F23 = 3.6347   F12 =16.4501   PN = .8862   PNPSI = .8862   DPHI2 = .1430E+06
T = .00154      PHI = 198.50   PHIDOT = 97.33   G =-.0038   GDOT = 25.88   PSID = 295.85   PSIDOT = -187.34   PHITOT = 18.50
                F23 = 3.6351   F12 =16.4513   PN = .8854   PNPSI = .8854   DPHI2 = .1391E+06
T = .00155      PHI = 198.55   PHIDOT = 98.69   G =-.0035   GDOT = 26.32   PSID = 285.74   PSIDOT = -190.86   PHITOT = 18.55
                F23 = 3.6395   F12 =16.4585   PN = .8751   PNPSI = .8751   DPHI2 = .1314E+06
T = .00156      PHI = 198.61   PHIDOT = 99.99   G =-.0032   GDOT = 26.75   PSID = 285.63   PSIDOT = -194.32   PHITOT = 18.61
                F23 = 3.6399   F12 =16.4598   PN = .8743   PNPSI = .8743   DPHI2 = .1275E+06
T = .00157      PHI = 198.67   PHIDOT = 101.24   G =-.0030   GDOT = 27.17   PSID = 285.52   PSIDOT = -197.70   PHITOT = 18.67
                F23 = 3.6444   F12 =16.4672   PN = .8636   PNPSI = .8636   DPHI2 = .1197E+06
T = .00158      PHI = 198.73   PHIDOT = 102.43   G =-.0027   GDOT = 27.57   PSID = 285.40   PSIDOT = -201.03   PHITOT = 18.73
                F23 = 3.6448   F12 =16.4684   PN = .8628   PNPSI = .8628   DPHI2 = .1158E+06
T = .00159      PHI = 198.78   PHIDOT = 103.55   G =-.0024   GDOT = 27.97   PSID = 285.28   PSIDOT = -204.28   PHITOT = 18.78
                F23 = 3.6493   F12 =16.4759   PN = .8519   PNPSI = .8519   DPHI2 = .1081E+06
T = .00160      PHI = 198.84   PHIDOT = 104.63   G =-.0021   GDOT = 28.35   PSID = 285.17   PSIDOT = -207.46   PHITOT = 18.84
                F23 = 3.6498   F12 =16.4772   PN = .8510   PNPSI = .8510   DPHI2 = .1043E+06
T = .00161      PHI = 198.90   PHIDOT = 105.64   G =-.0018   GDOT = 28.72   PSID = 285.05   PSIDOT = -210.57   PHITOT = 18.90
                F23 = 4.0030   F12 =16.4970   PN = .7074   PNPSI = .7074   DPHI2 = .4582E+05
T = .00162      PHI = 198.97   PHIDOT = 106.51   G =-.0015   GDOT = 29.06   PSID = 284.93   PSIDOT = -213.45   PHITOT = 18.97
                F23 = 4.0034   F12 =16.4981   PN = .7066   PNPSI = .7066   DPHI2 = .4268E+05
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T = .05584   PHI = 188.81    PHIDOT = 760.80   PSI = 285.70   PSIDOT = 270.26   PHITOT =1598.84
             FF12 = 17.005    FF23 =  4.260
T = .05584   PHI = 188.8[illegible]  PHIDOT = 764.10   PSI = 285.71   PSIDOT = 270.01   PHITOT =1598.86
             FF12 = 16.996    FF23 =  4.266
T = .05584   PHI = 188.89    PHIDOT = 767.40   PSI = 285.72   PSIDOT = 269.76   PHITOT =1598.89
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             FF12 = 16.988    FF23 =  4.271
T = .05584   PHI = 188.95    PHIDOT = 774.07   PSI = 285.74   PSIDOT = 269.26   PHITOT =1598.95
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T = .05584   PHI = 189.00    PHIDOT = 780.73   PSI = 285.76   PSIDOT = 268.76   PHITOT =1599.00
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T = .05584   PHI = 189.03    PHIDOT = 784.17   PSI = 285.77   PSIDOT = 268.51   PHITOT =1599.03
             FF12 = 16.970    FF23 =  4.283
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             FF12 = 16.970    FF23 =  4.283
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             FF12 = 16.952    FF23 =  4.295
T = .05585   PHI = 189.17    PHIDOT = 801.29   PSI = 285.81   PSIDOT = 267.25   PHITOT =1599.17
             FF12 = 16.951    FF23 =  4.294
T = .05585   PHI = 189.20    PHIDOT = 804.77   PSI = 285.82   PSIDOT = 267.00   PHITOT =1599.20
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T = .05585   PHI = 189.35    PHIDOT = 822.16   PSI = 285.87   PSIDOT = 265.74   PHITOT =1599.35
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T = .05585   PHI = 189.38    PHIDOT = 825.62   PSI = 285.88   PSIDOT = 265.49   PHITOT =1599.38
             FF12 = 16.970    FF23 =  3.864
T = .05585   PHI = 189.41    PHIDOT = 829.06   PSI = 285.89   PSIDOT = 265.24   PHITOT =1599.41
             FF12 = 16.970    FF23 =  3.864
T = .05585   PHI = 189.44    PHIDOT = 832.50   PSI = 285.90   PSIDOT = 264.99   PHITOT =1599.44
             FF12 = 16.979    FF23 =  3.868
T = .05585   PHI = 189.46    PHIDOT = 835.93   PSI = 285.91   PSIDOT = 264.74   PHITOT =1599.46
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T = .05586   PHI = 189.62    PHIDOT = 852.93   PSI = 285.96   PSIDOT = 263.48   PHITOT =1599.62
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                 FF12 = 17.018   FF23 =   3.887
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                 FF12 = 15.247   FF23 =   3.896
    T =  .05586  PHI = 189.77    PHIDOT = 869.70   PSI = 286.00   PSIDOT =   262.23   PHITOT =1599.77
                 FF12 = 15.247   FF23 =   3.896
    T =  .05586  PHI = 189.80    PHIDOT = 872.62   PSI = 286.01   PSIDOT =   261.98   PHITOT =1599.80
                 FF12 = 15.411   FF23 =   4.336
    T =  .05586  PHI = 189.83    PHIDOT = 875.47   PSI = 286.02   PSIDOT =   261.73   PHITOT =1599.83
                 FF12 = 15.411   FF23 =   4.336
    T =  .05586  PHI = 189.86    PHIDOT = 878.33   PSI = 286.03   PSIDOT =   261.47   PHITOT =1599.86
                 FF12 = 15.401   FF23 =   4.331
    T =  .05586  PHI = 189.90    PHIDOT = 881.20   PSI = 286.04   PSIDOT =   261.22   PHITOT =1599.90
                 FF12 = 15.401   FF23 =   4.331
    T =  .05586  PHI = 189.93    PHIDOT = 884.09   PSI = 286.05   PSIDOT =   260.97   PHITOT =1599.93
                 FF12 = 15.390   FF23 =   4.326
    T =  .05586  PHI = 189.96    PHIDOT = 886.98   PSI = 286.06   PSIDOT =   260.72   PHITOT =1599.96
                 FF12 = 15.390   FF23 =   4.326
    T =  .05586  PHI = 189.99    PHIDOT = 889.89   PSI = 286.07   PSIDOT =   260.47   PHITOT =1599.99
                 FF12 = 15.379   FF23 =   4.321
    T =  .05586  PHI = 190.02    PHIDOT = 892.80   PSI = 286.08   PSIDOT =   260.22   PHITOT =1600.02
                 FF12 = 15.379   FF23 =   4.321

      F23MAX =  5.20

      F12MAX = 19.32

      FF23MAX =  4.60

      FF12MAX = 18.19

      PNMAX =  1.20

      TURNS= 27.93
```

APPENDIX E

FRICTION FORCES DURING GEAR TRAIN MOTION REVERSAL

Since all friction forces of the escape wheel to rotor gear train reverse direction during a possible motion reversal following an impact, the introduction of a negative coefficient of friction, i.e., a $-\mu$, will satisfy for computational purposes the associated force and moment equilibrium expressions. (This method need not be resorted to for the pallet-escape wheel interface, since there motion reversal is accounted for by the signum function s_4.)

The above will be proven to hold for both the tooth contact and the pivot friction.

Tooth Contact Friction

The direction of the friction force of the pinion on a gear of a mesh is the same as that of the relative velocity of the contact point on the pinion with respect to the contact point on the gear (ref E-1). This relative velocity is obtained by way of the vector equation

$$\bar{V}_{C_p} = \bar{V}_{C_p/C_g} + \bar{V}_{C_g} \tag{E-1}$$

where (fig. E-1)

$\bar{V}_{C_p}$ = absolute velocity of contact point C_p of pinion tooth, with direction normal to line connecting pivot point O_p and contact point C_p (contact points C_p and C_g are coincident)

$\bar{V}_{C_g}$ = absolute velocity of contact point C_g of gear tooth with direction normal to the line connecting the pivot point O_g and the contact point C_g

$\bar{V}_{C_p/C_g}$ = relative velocity between contact points C_p and C_g. The direction of this velocity is normal to the line of action T_g-T_p.

Velocity triangles according to equation E-1 for contact of a simple mesh above and below the pitch point for two cases is shown in figure E-1. In figure E-1(a), the gear is the driver. In figure E-1(b), where the motion is reversed, the pinion becomes the driver. Figures E-1(a) and E-1(b) differ with respect to the direction of the relative motion, and with that, the direction of the contact friction force for comparable contact. This difference in the direction of the friction force may be expressed by reversing the sign of the friction force. For computer purposes, this is best accomplished by making μ positive when the gear is the driver and making it negative when the pinion becomes the driver. The normal force between the gear and the pinion, which has the direction of the line of action, is not dependent on the driver.

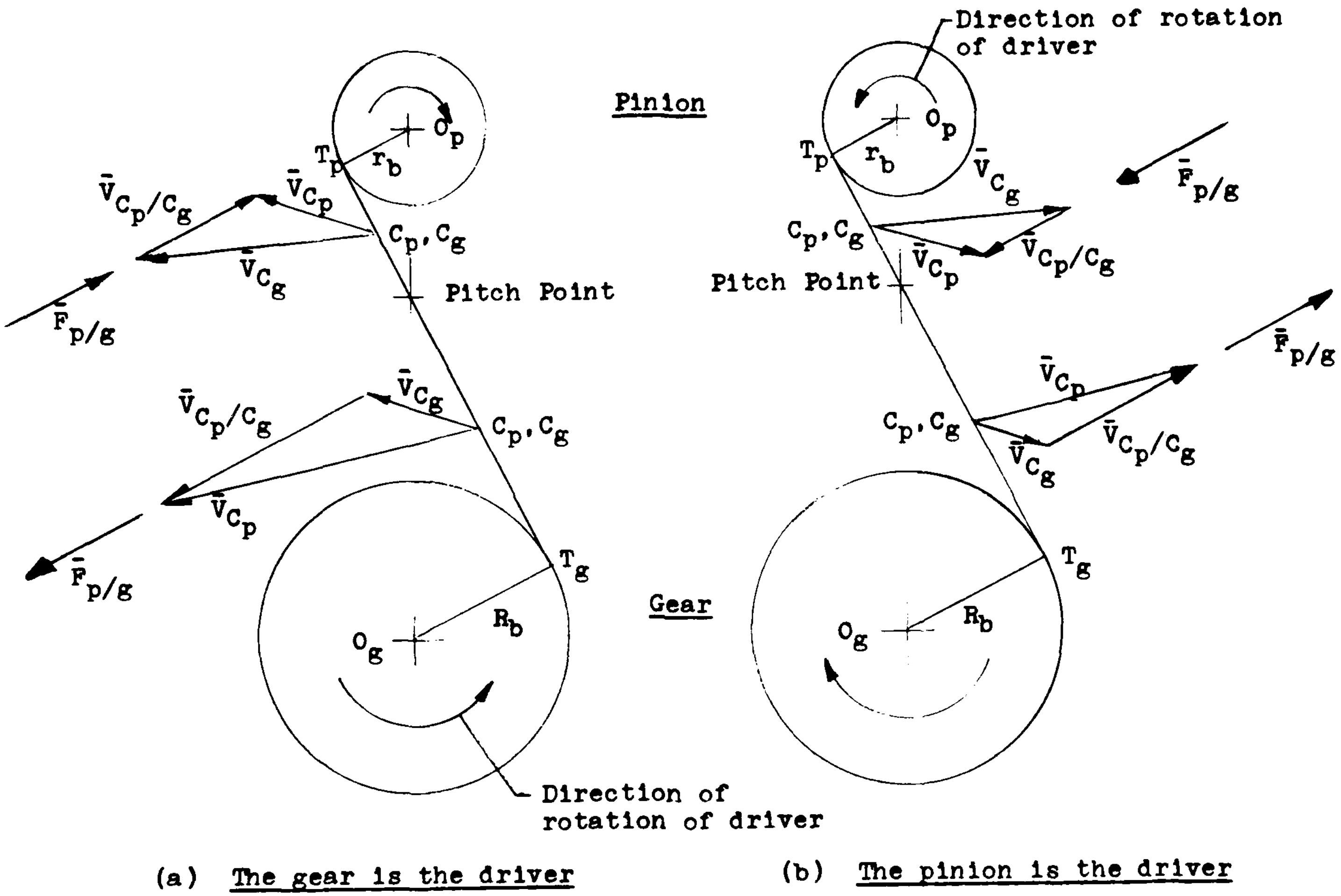

Figure E-1. Direction of friction force $\overline{F}_{p/g}$ of pinion on gear above and below pitch point as a function of driver

Pivot Friction

The free body diagram of the combined gear and pinion set no. 2 in clockwise rotation is shown in figure E-2. The associated equilibrium equations B-59 and B-60, which are used here as a general example, may be rewritten in the following manner:

$$F_x + \mu F_y = A_1 + \mu F_{23}COS2 - \mu F_{12}COS1 \quad (E-2)$$

and

$$-\mu F_x + F_y = A_2 + \mu F_{23}SIN2 - \mu F_{12}SIN1 \quad (E-3)$$

where A_1 and A_2 stand for the normal tooth contact and pivot forces which do not contain the coefficients of friction and do not change direction on motion reversal.* The trigonometric functions refer to the associated angles $\beta_1 - \theta_1$ and $\beta_2 + \theta_2$. The signum functions s_1 and s_2 are omitted for the present discussion since their influence is not relevant in this context. They change the signs of all friction terms on the right sides of equations E-2 and E-3, depending on whether contact is made before or after the pitch point.

Assume now that the direction of the gear set is changed to be counterclockwise. This causes the tooth contact friction forces (as shown earlier) to be reversed in sign. Furthermore, the two pivot friction forces are also reversed in sign. The above force equilibrium equations now have changed signs in all friction terms, i.e.,

$$F_x - \mu F_y = A_1 - \mu F_{23}COS2 + \mu F_{12}COS1 \quad (E-4)$$

and

$$\mu F_x + F_y = A_2 - \mu F_{23}SIN2 + \mu F_{12}SIN1 \quad (E-5)$$

Clearly, this effect of the change of the direction of all friction forces can be expressed by making the coefficient of friction negative for computational purposes.

---

* Equation A-2, reference E-1 shows that if the assumptions of the directions of the normal pivot forces prove wrong, the associated friction forces still furnish friction moments which have the appropriate direction of rotation.

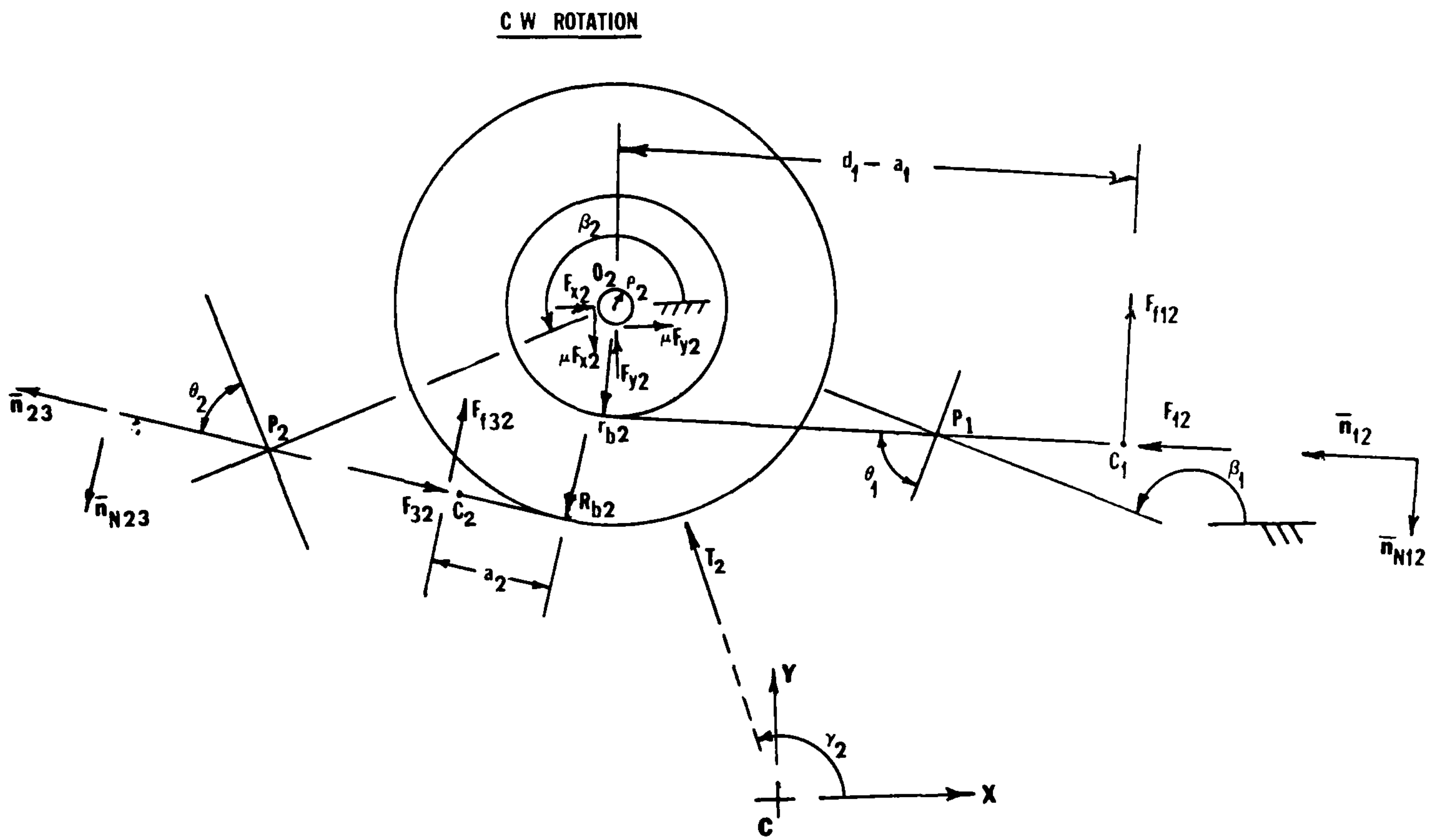

Figure E-2. Free body diagram of gear and pinion set no. 2

This idea also holds true in general for the moment equation and is illustrated with the help of the moment equation B-58 for gear and pinion set no. 2, which for clockwise rotation is of the following general form:

$$B - \mu F_{23} a_2 + \mu F_{12}(d_1 - a_1) + \mu \rho_2(\tilde{F}_{x2} + \tilde{F}_{y2}) = I_2 N_{32} \ddot{\phi} \qquad \text{(E-6)}$$

where B is similar to A_1 and A_2 in equations E-2 and E-3 by representing moment terms which do not contain the coefficient of friction, and whose sign does not change on motion reversal. In the same vein, the signum functions s_1 and s_2 are omitted.

If the direction of rotation is counterclockwise, the above expression becomes

$$B + \mu F_{23} a_2 - \mu F_{12}(d_1 - a_1) - \mu \rho_2(\tilde{F}_{x2} + \tilde{F}_{y2}) = I_2 N_{32} \ddot{\phi} \qquad \text{(E-7)}$$

Thus, the change in the direction of the friction moments can also be expressed by making the coefficient of friction negative for computational purposes.

Finally, the results of these new force and moment equations for the various components may be obtained by changing the signs of all coefficients of friction in the results of the original expressions which were derived for forward motion of the train.

REFERENCE

E-1. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, US Army ARRADCOM, Dover, NJ, December 1979.

APPENDIX F

A COMPUTATIONAL RULE FOR THE DETERMINATION OF THE SIGN IN THE EFFECTIVE MOMENT OF INERTIA I_{iR}

Whenever the center of mass of a fuze train component, such as a pallet or a rotor, does not coincide with its pivot axis, there will be a pivot friction moment which is proportional to the angular acceleration of the component. Just like any other friction moment, its direction must be opposite to the angular velocity of such a rotating part. The following shows how the appropriate choice of the sign in the expression for the effective moment of inertia I_{iR}* of the component assures that this friction moment will always retard motion. While this discussion holds in general, it makes specific use of the pallet moment equation A-78, appendix A. This expression becomes in condensed form

$$M_S \pm M_{AA} = I_p \ddot{\psi} \qquad \text{(F-1)}$$

where

M_S = the sum of all moments on the pallet, with the exception of the friction moment M_{AA} which is proportional to the angular acceleration $\ddot{\psi}$ of the pallet. The moment M_S is sufficiently larger than the moment M_{AA} so that it will at all times decide the direction of the angular acceleration $\ddot{\psi}$

$$M_{AA} = \mu_1 \rho_p (A_4 + A_8) \ddot{\psi} = A_{22} \ddot{\psi} \qquad \text{(F-2)}$$

i.e., A_{22} is always positive. Note also that the signum function s_5 has been omitted.

Figure F-1, a through d represents free body diagrams of a simplified pallet, or rotor, with various directions of $\dot{\psi}$, M_S, and M_{AA}.

In figure F-1a the moment M_S is assumed to be CCW, i.e., positive. The angular velocity $\dot{\psi}$ is also assumed to be positive and therefore the friction moment must be negative. Equation F-1 becomes

$$M_S - M_{AA} = I_p \ddot{\psi} \qquad \text{(F-3)}$$

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* The letter i in the subscript stands for the component number or letter.

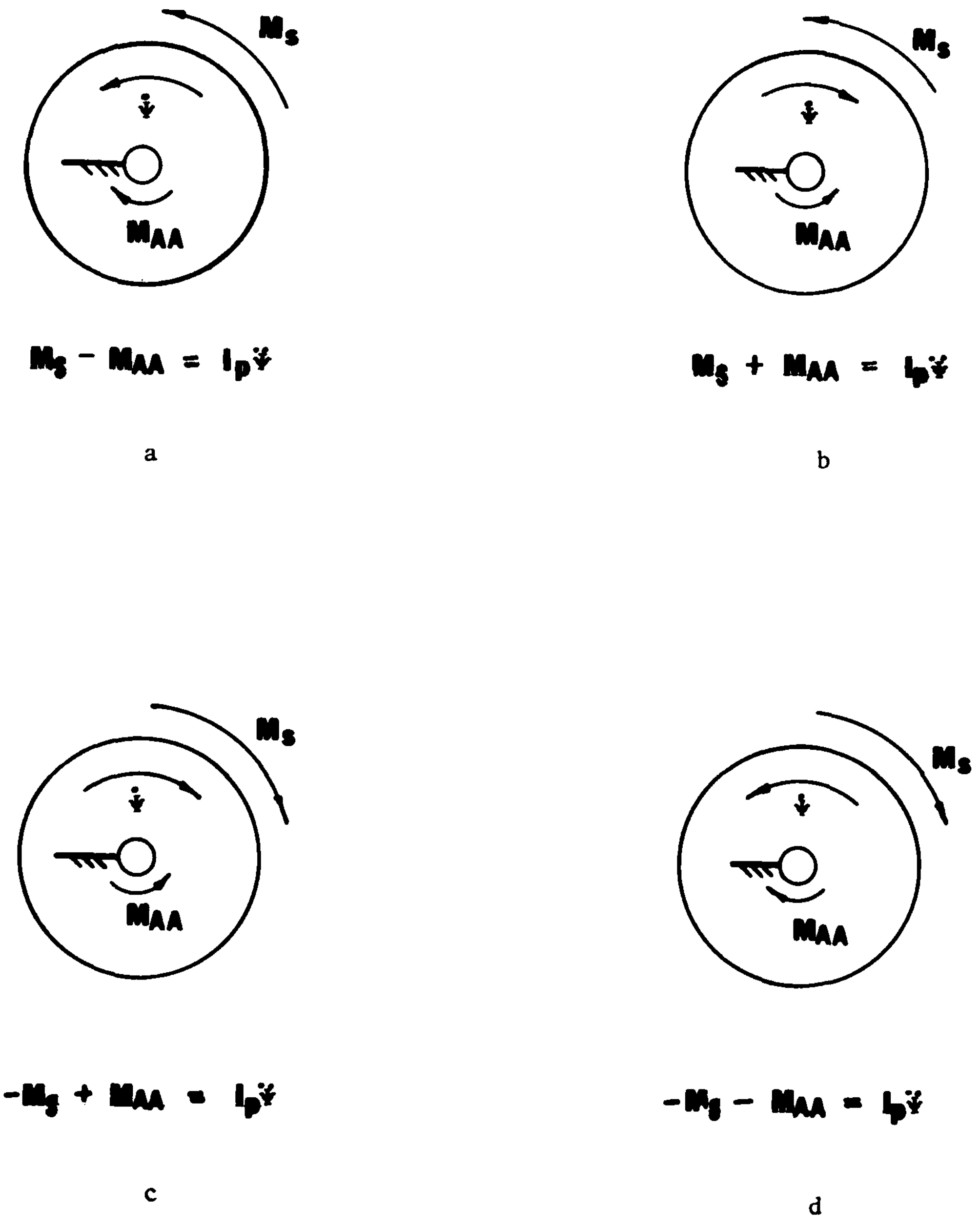

Figure F-1. Free body diagram of simplified pallet or rotor

In general, the sign of $\ddot{\psi}$ is never predetermined in a differential equation of this type, but it is decided by the sign of the resultant moment. In this specific work it must be remembered that the direction of $\ddot{\psi}$ is decided by M_S alone and that the friction moment M_{AA} must act opposite to the direction of the angular velocity $\dot{\psi}$.

If equation F-2 is substituted into the above expression with a positive $\ddot{\psi}$, it becomes

$$M_S = \ddot{\psi}(I_p + A_{22}) \tag{F-4}$$

Let equations F-3 and F-4 now be used to find equivalent expressions for the angular acceleration $\ddot{\psi}$. Thus, from equation F-3

$$\ddot{\psi} = \frac{M_S - M_{AA}}{I_p} \tag{F-5}$$

and from equation F-4

$$\ddot{\psi} = \frac{M_S}{I_p + A_{22}} \tag{F-6}$$

In the first form the absolute value of the angular acceleration is reduced, from the value it would attain due to the moment M_S alone, by the presence of M_{AA}. In the second form, which must be used in the computations, $\ddot{\psi}$ is reduced in absolute magnitude by the equivalent presence of a larger effective moment of inertia $I_{PR} = I_p + A_{22}$. (The subscript PR is used for the pallet.)

Now consider the condition of figure F-1b where M_S is also positive, but $\dot{\psi}$ is negative, and with that M_{AA} must be positive. This leads to the following moment equation:

$$M_S + M_{AA} = I_p \ddot{\psi} \tag{F-7}$$

or, with equation F-2 and a positive $\ddot{\psi}$

$$M_S = \ddot{\psi}\,(I_p - A_{22}) \tag{F-8}$$

The above expressions are again used to find two equivalent forms for $\ddot{\psi}$. From equation F-7 one obtains

$$\ddot{\psi} = \frac{M_S + M_{AA}}{I_p} \tag{F-9}$$

while equation F-8 gives

$$\ddot{\psi} = \frac{M_S}{I_p - A_{22}} \tag{F-10}$$

In the first form the absolute value of $\ddot{\psi}$ is increased by the added presence of M_{AA} over that due to M_S alone. The second form shows this increase in $\ddot{\psi}$ by way of the reduced effective moment of inertia $I_{PR} = I_p - A_{22}$.

In figures F-1c and F-1d M_S is shown to act in a clockwise, i.e., negative direction, and with that $\ddot{\psi}$ is also negative. Consider the condition of figure F-1c first. The moment equation must take the negative $\dot{\psi}$ into account by way of a positive M_{AA}. Thus, from the free body diagram

$$- M_S + M_{AA} = I_p \ddot{\psi} \tag{F-11}$$

To keep all signs correct on substitution of equation F-2 and the negative $\ddot{\psi}$, the above expression must take the form

$$- M_S - A_{22} (-\ddot{\psi}) = I_p(-\ddot{\psi}) \tag{F-12}$$

or

$$- M_S = -\ddot{\psi}(I_p + A_{22}) \tag{F-13}$$

The absolute value of $\ddot{\psi}$ is then given by

$$\ddot{\psi} = \frac{M_S}{I_p + A_{22}} \tag{F-14}$$

Again, this value is reduced in absolute magnitude by the increase of the effective moment of inertia to $I_{PR} = I_p + A_{22}$. This is the equivalent to a decrease in the absolute value of the resultant moment.

Figure F-1d shows the pivot friction moment M_{AA} in the same direction as M_S since $\dot{\psi}$ is positive. The moment equation becomes

$$-M_S - M_{AA} = I_p \ddot{\psi} \tag{F-15}$$

Upon substitution of equation F-2 together with the negative $\ddot{\psi}$, one finds

$$-M_S + A_{22}\,(-\ddot{\psi}) \;=\; I_p(-\ddot{\psi}) \qquad \text{(F-16)}$$

or

$$-M_S = -\,\ddot{\psi}(I_p - A_{22}) \qquad \text{(F-17)}$$

The absolute value of $\ddot{\psi}$ now becomes

$$\ddot{\psi} = \frac{M_S}{I_p - A_{22}} \qquad \text{(F-18)}$$

It is increased by the decrease in the effective moment of inertia to $I_{PR} = I_p - A_{22}$.

These four cases allow the following computational rule for the determination of the sign of the parameter A_{22} in the effective moment of inertia.

From the equations F-6 and F-14, together with the associated figures F-1a and F-1c, respectively

$$I_{PR} = I_p + A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have identical signs} \qquad \text{(F-19)}$$

Further, from equations F-10 and F-18, together with the associated figures F-1b and F-1d, respectively

$$I_{PR} = I_p - A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have opposite signs} \qquad \text{(F-20)}$$

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